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BUS OPERATIONS IN SANTA CLARA COUNTY, POTENTIAL USES OF AVL, AND FRAMEWORK FOR EVALUATING CONTROL STRATEGIES

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ABSTRACT

The Santa Clara Valley Transportation Authority (VTA), which provides public transportation to citizens of Santa Clara county, California, operates buses, light rail, and paratransit service. The VTA is currently installing automatic vehicle location (AVL) equipment on its bus fleet. This report presents the results of Phase 1 research, which examines the various performance and operational characteristics of the fixed-route bus system operated by the VTA. The purpose is to identify performance characteristics of the bus system that should and could be improved with and without utilizing AVL. Characteristics examined include: schedule adherence, transfer coordination, passenger waiting time, and passenger information need. Possible control strategies for improving performance and operational characteristics of the bus system are identified. An evaluation framework for assessing the potential benefits/costs of alternative strategies for improving transit performance and operational characteristics is also developed. This research was based on empirical evidence collected through field observations, interviews with the VTA's transit personnel, VTA's records, a survey of bus riders, and a literature review.

Key Words:

transit, bus, schedule adherence, transfer coordination, control strategy, passenger waiting time, passenger information, transit information, transit performance, automatic vehicle location, AVL.

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PREFACE

Many individuals at the Institute of Transportation, Berkeley, contributed to the completion of this research. Ted Chira-Chavala directed the study and wrote chapters one through four. David Gillen developed the methodology for, and wrote, the evaluation framework chapter (chapter five). Lee Klieman conducted a literature review. He assisted in the field observations and interviews of VTA's personnel, and contributed to chapters one through four. Amy Marshall assisted in field observations and directed the distribution of the survey questionnaires. Arron Golub and Douglas Cooper assisted in field observations.

Thanks are due for personnel of the planning and operations department of Santa Clara Valley Transportation Authority (VTA), who met with and provided information to the research team.

Views and opinions expressed in this report are those of the authors, and do not necessarily reflect the views of the VTA or the research sponsor (Caltrans).

EXECUTIVE SUMMARY

Statement of the Problem

The Santa Clara Valley Transportation Authority (VTA) is responsible for public transportation system in Santa Clara county. The county's transit system is comprised of buses, light rail, and paratransit service. The VTA operates its own buses and light rail vehicles, and contracts with OUTREACH to provide paratransit service in accordance with the requirements of the Americans-With-Disabilities Act (ADA).

Automated vehicle location (AVL) equipment has already been installed on paratransit vans. In-depth studies were recently completed on the operational, performance, and safety characteristics of the VTA's light-rail and paratransit systems. However, an in-depth study of the VTA's bus system has not been conducted.

In 1997, the VTA received funding from the Federal Transit Administration (FTA) to install automated vehicle location (AVL) equipment on its bus fleet. AVL on both the buses and paratransit vehicles provides a tremendous opportunity for the VTA to significantly improve the performance and productivity of its overall public transportation system. Initially, after the AVL installation on buses is completed, research will be needed to test and implement control strategies utilizing AVL to begin to improve schedule adherence, transfer coordination, passenger information, and driver/dispatcher information of the bus system. At the present time, efforts between OUTREACH and the Institute of Transportation Studies at Berkeley are already underway to study strategies for improving on-time performance of paratransit vehicles equipped with AVL. A longer-term goal will be to identify strategies for implementing real-time interfaces between the AVL-equipped buses, light rail system, and AVL-equipped paratransit vehicles. This integrated system would enable the VTA to reduce the cost of providing paratransit service and to increase the utilization of the fixed-route systems.

At this time, strategies utilizing AVL for improving the performance of bus systems and for achieving real-time interfaces between fixed-route transit and paratransit systems are not well understood. Neither is the proportion of ADA paratransit users who are physically able to use fixed-route systems as part of their journey.

In the meantime, there is a need to first obtain good, in-depth understanding of the performance characteristics of the VTA's bus system (such as passenger information, driver/dispatcher information, schedule adherence, and transfer coordination among different bus routes), and current bus operation practices related to schedule adherence and transfer coordination. In this way, performance characteristics of the VTA's bus system that should and can be improved (with and without AVL) may be identified. This is the focus of this Phase 1 research.

Objectives of This Report

The objectives of this Phase 1 research were to: (i) examine the existing schedule adherence, transfer coordination, passenger waiting time, and passenger information of the VTA's bus system; (ii) identify possible control strategies for improving these performance characteristics; (iii) assess the information needs of VTA's bus riders; and (iv) develop an evaluation framework for assessing the potential benefits/costs of alternative strategies with and without AVL for improving transit performance characteristics.

VTA's Bus System

The VTA's bus system consists of 72 fixed routes. Service frequencies for main commuter routes range from 10 to 20 minutes during peak hours, and 30 minutes during off-peak hours. Service frequencies for feeder routes are 30 and 60 minutes during peak and off-peak hours, respectively.

Research Approach

This research was based primarily on analyzing empirical evidence collected through field observations of VTA's bus routes, interviews with the VTA's transit personnel, a survey of bus riders, and a literature review.

Principal Findings

Schedule Adherence of VTA's Bus System

Route 22 (with 10-minute service headway) and Route 26 (with 20-30 minute headway) were selected for in-depth investigations. They have highest riderships among all VTA's bus routes. Field observations indicate that they both had schedule adherence problems, and that there were similarities as well as differences in these problems between the two routes.

First, contributing factors for late buses on the two routes were quite similar: traffic congestion, delays at numerous traffic signals, unexpected passenger demand, handicapped passengers, and driver behaviors. There appeared to be little slack time in the timetables of both routes to enable most buses that were up to four minutes late to make up time on their own without external intervention.

Once buses were late by more than four minutes, it might be difficult to become on-time again. For Route 22 with service headways of 10 minutes, the most common trend was that the lateness of such buses tended to be amplified downstream. For longer service headways (20-30 minutes) such as Route 26, once buses were late by more than four minutes, this level of lateness tended to be maintained throughout or the initial lateness may be slightly amplified downstream. It appeared that longer service headways were associated with a lower probability of amplification of bus lateness than smaller headways.

Bus bunching was a common problem for Route 22, but not for Route 26. This is probably due to the longer service headways of the latter. We also found that it was easier for late buses on routes with longer service headways to make up the lost time on their own than late buses with shorter service headways.

VTA's Current Efforts to Maintain Bus Schedule Adherence

The following strategies were currently used by the VTA to address bus schedule deviation problems: schedule-based holding (but not headway-based holding); drivers informing supervisors if buses become more than five minutes late, and supervisor instructing drivers of late buses to take appropriate actions (e.g., dropping passengers off only); and inserting an additional bus into service.

VTA's Current Bus Transfer Coordination Practice

The VTA currently has limited timed transfer operations, only for routes with service headways of 60 minutes in the evening. In this regard, the VTA generally incorporates extra layover times (around 6 minutes) at transfer points in timetables of connecting bus routes.

Observed average waiting time for passengers transferring from other routes to Route 26 was found to be as high as 68% of the value of Route 26's scheduled headway. This suggests that there is room for improving transfer coordination between VTA's bus routes, so that passenger delays may be reduced.

Passenger Waiting Times

For bus routes with small service headways (10 minutes), we found that about two-thirds of passengers tended to ignore the bus timetables and arrive at bus stops at random. As service headways increased, the percent of random arrivals at bus stops decreased while the percent of people looking up bus timetables beforehand increased.

We found that average waiting time at bus stops and the standard deviation for people who knew bus timetables beforehand was smaller than those for people who came to bus stops at random, as expected.

VTA's Existing Transit Information for passengers

The VTA currently provides information to bus riders via printed timetables and maps, telephone information system, and electronic information system (accessible via personal computers).

We conducted a survey of bus riders to determine their information needs. We found that:

- Regular bus riders were highly enthusiastic about real-time displays of bus arrival times at bus stops. They also highly valued conventional bus timetables and route maps posted at bus stops and inside the bus, more so than having this information via telephone or personal computers.
- Infrequent bus riders were also highly enthusiastic about real-time displays of bus arrival times at bus stops.
- Female riders valued in-vehicle announcements (upcoming bus stop, transfer stop, and departure time of connecting routes) much more than male riders, probably due to the former's concern about personal safety at bus stops for themselves and accompanied children.

Possible Control Strategies for Bus Schedule Adherence

Several control strategies can be used for improving bus schedule adherence with or without real-time information from AVL: realistic bus schedules, priority traffic signal timing for buses, signal pre-emption for late buses, exclusive bus lanes, schedule-based and headway-based vehicle holding at control points, "pre-fol" vehicle holding, supervisory interventions (e.g., changing bus speed, leapfrog, skipping stops, closed-door operation, short-turning operation), inserting additional buses, modifying bus route structure, driver monitoring, driver incentives, and comprehensive team approach. However, real-time information from AVL would be ideal in facilitating the implementations of these strategies and increasing their effectiveness.

Possible Control Strategies for Bus Timed Transfer

Many possible control strategies can be used for achieving bus timed transfers, and real-time information from AVL would be ideal in facilitating their implementation and increasing their effectiveness. They include: coordinating timetables of connecting bus routes, vehicle holding at transfer points without communications between drivers and without supervisory intervention, vehicle holding with supervisory intervention at transfer points, vehicle holding at transfer points with communications among drivers, and real-time dispatching control at transfer points.

Strategy for Providing Real-Time Bus Arrival Information

Maximum benefits of real-time displays of bus arrival information at bus stops are likely to occur for bus routes with high service frequencies and high passenger demand. This is because it is usually more difficult for such bus routes to maintain schedule adherence. Therefore, this kind of bus routes should receive priorities in implementing real-time displays of bus arrival information. However, real-time bus arrival information is not a substitute for bus service reliability. Transit agencies should utilize AVL to improve bus service reliability first, then attempt to improve service quality further by providing real-time bus arrival information to passengers later.

Finally, we developed an evaluation framework for evaluating the benefits and costs of alternative control strategies (with and without AVL) for improving transit performance and efficiency. This chapter can be a stand-alone document.

CHAPTER ONE
INTRODUCTION

The Santa Clara Valley Transportation Authority (known as VTA) provides public transportation services to residents of Santa Clara county. The county's public transportation system is vast and extensive, and is comprised of buses, light rail, and paratransit service, as follows.

The Paratransit System

VTA, through its paratransit broker OUTREACH, provides door-to-door paratransit service to the county residents in accordance with the 1990 Americans With Disabilities Act (ADA). The paratransit operation makes use of accessible vans (equipped with wheelchair facilities) and taxis. The service is extensive and cover all 15 cities of the county. Each year it provides about 800,000 trips to about 10,000 ADA-eligible individuals. In 1995, OUTREACH automated its paratransit scheduling function. Since then, it has also been installing automated vehicle location (AVL) equipment on paratransit vans. At the present time, at least 40 vans have the AVL equipment to provide status and locations of vehicles in real-time.

The Institute of Transportation Studies, University of California at Berkeley, was involved in the deployment of the automated paratransit scheduling system and installations of AVL on paratransit vans. A study report by Chira-Chavala et al (1997) described the deployments of these advanced technologies in detail, together with service quality and performance characteristics of the paratransit system.

The Light Rail System

The VTA's light rail system began operation in 1987. It is 20 miles long, and serves the City of San Jose in a north-south direction. An in-depth study of the VTA's light-rail system (Chira-Chavala et al, 1997) was completed in 1997. This study fully described the operational, performance, and safety characteristics of the light-rail system.

The Bus System

The VTA's bus system consists of 72 fixed routes (14 grid, 23 crosstown, 21 feeder, and 14 express routes), and serves a population of 1.6 million and 326 square-miles of urban areas. A fleet of 460 buses carries a total daily ridership of about 140,000 passengers. The sheer size of the bus network and service area, as well as the bus route patterns, require some transfers among different bus routes.

Service frequencies for the VTA's commuter bus routes are fairly good, every 10-20 minutes during peak hours and every 30 minutes during off-peak hours. For feeder routes, service frequencies are 30 minutes during peak hours and 60 minutes during off-peak hours. No VTA's bus operates less frequently than every 60 minutes.

Potential Uses of AVL for VTA's Public Transportation System

In 1997, the VTA received funding from the Federal Transit Administration (FTA) to install automated vehicle location (AVL) equipment on its bus fleet. The installation of AVL on VTA's buses is still ongoing. Once this is completed, the AVL systems on both the buses and paratransit vans provide a tremendous opportunity for the VTA to significantly improve the performance and productivity of its overall public transportation system. Initially, there is a need to identify, test, and implement promising control strategies to significantly improve schedule adherence, transfer coordination, passenger information, and driver/dispatcher information of VTA's bus system. At the present time, efforts between OUTREACH and ITS-Berkeley are underway to identify and implement strategies to improve on-time performance of the AVL-equipped paratransit vehicles. In the longer term, research is needed to identify and implement real-time interfaces between the AVL-equipped buses, AVL-equipped paratransit vehicles, and light rail system. Such a real-time integrated system would enable the VTA to reduce the cost of providing paratransit service and to increase the utilization of the fixed-route systems.

Evidence in the literature indicates that bus operators with AVL generally have not made full or effective use of the AVL capabilities, including to improve passenger information, driver/dispatcher information, schedule adherence, and transfer coordination. This is because strategies utilizing AVL for these purposes are still not well understood. Rather, AVL systems are mostly used for security and service monitoring purposes.

Incremental Research

An eventual integration of fixed-route transit and paratransit systems utilizing AVL in Santa Clara County calls for incremental R&D activities. In the first phase, there is an immediate need to obtain good understanding of the performance characteristics of the VTA's bus system, particularly those that could be improved by use of AVL such as: passenger information, driver/dispatcher information, schedule adherence, and transfer coordination among different bus routes. Further, there is also a need to understand VTA's current practices of schedule adherence and transfer coordination of its bus system. Unlike the VTA's paratransit and light rail systems, there is a lack of in-depth studies that systematically examines the operational and performance characteristics of the VTA's bus system. This is the focus of this phase of the research and this final report.

In the second phase, once AVL installation on the VTA's buses is completed, there is a need to identify, test, and implement promising control strategies to improve performance of the bus system (e.g., passenger information, driver/dispatcher information, schedule adherence, and transfer coordination) as well as to implement promising strategies to improve the on-time performance of paratransit vehicles.

Once this second phase is accomplished, further research will be needed to develop and implement a strategy to integrate the VTA's paratransit service with the bus and light rail systems.

OBJECTIVE OF THIS REPORT

The objectives of this Phase 1 research and this study report were manyfold:

- To examine of the various existing performance and operational characteristics of the VTA's bus system that may be improved by AVL capabilities; for example: schedule adherence; transfer coordination among different bus routes; passenger waiting time characteristics; and passenger information.
- To suggest possible control strategies for improving bus schedule adherence, transfer coordination among different bus routes, and transit information for passengers.
- To determine the information needs of VTA's bus riders.

- To develop an evaluation framework for assessing the potential benefits/costs of alternative strategies with and without AVL for improving transit performance characteristics.

RESEARCH APPROACH

To achieve the objectives, we collected empirical data on the VTA's bus system through a number of means. We conducted field observations to study bus schedule adherence, transfer coordination, and passenger waiting time characteristics. We interviewed the VTA's transit planning and operations personnel to learn about current bus operation practices. We conducted a survey of the VTA's bus riders to obtain their perceptions of transit information needs.

We conducted an extensive literature review to identify possible control strategies for improving bus schedule adherence, transfer coordination, and passenger information. Finally, we developed an evaluation framework for use in assessing the benefits and costs of alternative strategies with and without AVL for improving transit performance.

ORGANIZATION OF THIS REPORT

This report is organized into several chapters. Chapter two describes existing schedule adherence, transfer coordination, passenger waiting time characteristics of the VTA's bus system. It also describes current practices that the VTA uses in assuring schedule adherence and timed transfer. Chapter three describes the results of a survey to determine transit information needs of VTA's bus riders, as well as a strategy for implementing real-time information for bus riders. Chapter four describes possible strategies for improving bus schedule adherence and timed transfer. Chapter five presents an economic framework for evaluating the benefits and costs of alternative strategies with and without AVL for improving transit performance.

CHAPTER TWO

VTA's BUS SYSTEM PERFORMANCE

Important performance characteristics of fixed-route bus services include: on-time performance (or service reliability, schedule adherence); the ease and timeliness for passengers to transfer among different bus routes (transfer coordination); and passenger waiting times. These performance characteristics of the VTA's bus system were examined here in-depth, as follows.

OBSERVED BUS SCHEDULE ADHERENCE

Poor schedule adherence inevitably results in passenger dissatisfaction, increased operating costs for the transit agency, and possibly ridership loss. Bus riders generally dislike long waits for buses at stops/stations. When buses do not run according to printed timetables, passengers waiting at bus stop often become anxious because they are uncertain about how long the delay may be and how may such delay affect their plans.

Adherence to printed timetables, defined as the difference between a vehicle’s scheduled departure time and actual departure time from a stop, is particularly desirable for bus routes with low service frequencies (i.e., when bus service headways are large). This is in order to minimize mis-connections for transfer passengers using low-frequency bus routes. Besides, most passengers wishing to use bus routes with low service frequencies tend to rely more on bus timetables (than those using high-frequency routes). If buses operating infrequently are not on-time, riders may have to wait at bus stops for a long time.

For bus routes with frequent service (headways less than 10 minutes), most passengers tend to pay less attention to printed timetables and generally arrive at bus stops at random, expecting small waiting times there. Therefore, for bus routes with service headways less than 10 minutes, the ability for buses to maintain a constant headway is important. Otherwise, service reliability is likely to deteriorate quickly, and bus bunching (i.e., a bus catching up to a bus in front) is likely to occur.

When schedule deviations occur, buses may be early or late. Late buses are more common, and more of a problem (than early buses) in terms of identifying corrective measures. Key factors contributing to poor on-time performance of buses are stochastic variations in bus trip time between stops and in passenger demand. The former is influenced by traffic-flow conditions, traffic signals, traffic incidents, pedestrian activities, and driver behavior. Variations in passenger demand affects dwell times at bus stops. For example: unusually large numbers of passengers boardings and alightings as well as disabled passengers inevitably increase dwell times at bus stops.

Ride-along observations were conducted to study schedule adherence of VTA's bus routes. Two routes were selected for observations -- Route 22 and Route 26. Both were selected because they had very high ridership and significant schedule adherence problems (in terms of total annual person-hours of delays incurred by buses not running on-time). They also had vastly different service headways. Route 22 had small headway (10 minutes all day), while Route 26 had 20- minute headway during peak hours and 30-minute headway during off-peak hours. Further, the VTA considered these two routes as having high priorities for schedule-adherence improvements due to high ridership and a high number of hours of passenger delays. Printed timetables for Route 22 and Route 26 specified bus departure times at designated time points along the route.

Schedule Adherence of Route 22

Route 22 is the busiest and longest bus route, with a daily ridership over 23,000. A one-way trip is 27 miles long and takes over two hours. Route 22 crosses the entire length of the VTA's service area in a northwest-southeast direction, and passes through the San Jose's central business district (CBD). It has the northwestern terminal at Menlo Park Caltrain Station and the southeastern terminal at the Eastridge shopping center in East San Jose. There are 15 time points along the route.

Bus ride-along observations involved an observer riding each bus from end to end to record various information on data collection forms: actual bus departure time from each time point, passenger load, numbers of passengers boarding and alighting, number of stops for passengers, number of stops at traffic signals, delay at traffic signal, general traffic-flow conditions, etc. Ride-along observations, which took place in February-October 1997, covered morning-peak, afternoon-peak, and off-peak hours. Twelve runs were completed -- seven during peak hours and another five during off-peak hours. We define a peak-hour run as that in which at least part of the trip took place between 7:00 and 9:00 am or 3:30 and 6:30 pm; otherwise it is considered an off-peak run.

Figure 2.1 and Figure 2.2 show schedule deviation profiles for seven eastbound and five westbound runs, respectively. In two of the seven peak-hour runs, the buses were mostly on-time. In the other five peak-hour runs, the buses showed significant schedule deviations. One of the five off-peak runs was mostly on-time, while the other four off-peak runs were not. This suggests that schedule deviations on Route 22 were common, and occurred during both peak and off-peak periods.

Bus runs that incurred at least four minutes of lateness at any time point along the route were examined in-depth. Three categories of schedule deviations were defined for these late buses, as follows:

Category A: The bus was late initially, but made up the lost time downstream later.

Category B: The bus was late, and maintained the same lateness without becoming worse downstream.

Category C: The bus was late, and became even more late downstream.

fig 2.1

fig 2.2

Of these categories, Category C was the dominant pattern for Route 22, while Category A was observed only during off-peak hours.

Category A Lateness

Category A lateness was observed for two off-peak runs, as follows:

(i) An eastbound bus departing from Menlo Park at 9:50 am, more or less on time. It was four minutes late after having traveled about the first one-fifth of the route (at El Camino & Page Mill and El Camino & Showers), due to a driver change which took four minutes and an unscheduled roadside stop (not at a bus stop) for twenty seconds with no apparent reason. After the Showers Street stop, the bus consistently gained time, and was able made up all of the lateness within the next three time points. After that, it remained on time through the San Jose CBD (Santa Clara/ First Street time point designates the middle of the CBD) and for the remainder of route. The onboard observer did not detect that the driver took any unusual measure to make up the lost time, but noted that traffic flow conditions were good and passenger loading was moderate.

(ii) A westbound run departing from Eastridge at 1:54, about two minutes late. The bus became 4 minutes late at the next time point. However, the bus quickly made up all lateness through the San Jose CBD and for the remainder of the route.

These two off-peak runs suggest that, during off-peak hours when traffic conditions were favorable, there was sufficient slack time in the Route 22's timetable to allow a bus that was late for four minutes to make up time without difficulty, provided that there was no unusual passenger boarding or alighting.

Category B Lateness

Category B lateness was observed on two runs (one during peak hours and the other during off-peak), as follows:

(i) An eastbound run departing from Menlo Park at 1:19 pm, more or less on time. The bus was six minutes late after having travelled the first one-fifth of the route (at El Camino & Page Mill and El Camino & Showers). This delay then increased to eight minutes at the next time point (at El Camino & Castro). A number of factors contributing to this: the driver stopped for 30 seconds by the roadside to remove a disruptive passenger; the bus made very frequent stops for passengers and at traffic signals. At one signalized intersection, the bus stopped for a full two minutes. Before El Camino & Castro, the driver noticed another bus right behind it. So he began dropping off passengers only, in order to put some distance between himself and the following bus. The driver moved into the middle lane of the road and sped up. After El Camino & Castro, the lateness decreased to about 4-5 minutes, until the bus reached the San Jose CBD when the lateness again increased to eight minutes. The bus was not able to make up the lost time through the CBD due to a number of factors: a disabled passenger required 30 seconds for boarding; frequent stops; long delays at traffic signals in the CBD; and the bus was not able to continue dropping off passengers only for very long. After leaving the CBD and until the end of the route, the bus lateness hovered around 6 minutes.

(ii) A westbound run departing from Eastridge at 7:13 am, more or less on time. It was seven minutes late at the first time point because it made very frequent stops for passengers and at traffic signals. Further, there was one disabled passenger requiring considerably extra time in boarding the bus. Later, the bus briefly made up some of the lost time but then began to lose time again due to: frequent stops at traffic signals, high numbers of passenger boardings, and one disabled passenger alighting.

These two runs suggest that once buses on Route 22 became quite late (by five or more minutes), it might be difficult for them to become on-time again. Both recurring and non-recurring events encountered along the route appeared to be the reasons. The former included frequent stops at traffic signals, frequent stops for passengers, and traffic congestion on the road. Non-recurring events included: higher than expected number of boardings, disabled passengers, and disruptive passengers.

Closer examinations of runs pertaining to Categories A and B suggest that: (a) there was probably slack time of up to four minutes in Route 22's timetable; and (b) once a bus was late by more than four minutes, it might be difficult to become on-time again for the remaining of the route.

Category C Lateness

Category C lateness was observed for seven out of the 11 late runs. It is typified by a bus being late initially for at least four minutes, then the lateness was amplified for the remaining of the route. The seven runs are described below.

(i) An eastbound run departing from Menlo Park at 4:01 pm, and was on-time for the first half of the route. Before the El Camino & Kiely time point, the bus overtook the preceding bus (which was running very late). Then, at the El Camino & Kiely time point, the driver stopped to allow the other bus to get back in front. The front bus then began dropping off passengers only (without pick-up). Consequently, the observed bus had to pick up passengers who had arrived during the last 20 minutes (instead of just those arriving during the last 10 minutes, had the preceding bus not been very late). At Monroe & Franklin, the bus was four minutes late. Later, the lateness increased due to: very frequent stops for passengers; afternoon traffic congestion in and around the CBD; delays at most signalized intersections in and around the CBD. The bus lateness finally increased to eight minutes toward the end of the route.

(ii) An eastbound run departing from Menlo Park at 4:29 pm on-time. It remained on-time for about two-third of the route until the Alameda & Naglee time point, just before entering the CBD. At that time point, the delay built up quickly. The reason was that the preceding bus was early and kept becoming more early downstream, leaving the observed bus to pick up more passengers than expected As the result, the observed bus was 16 minute late toward the end of the route.

(iii) An eastbound run departing Menlo Park at 1:38 pm on time, and was mostly on-time during the first half of the route. As it neared the San Jose CBD, it encountered heavy passenger demand (resulting in a full bus, with standing passengers). This added extra delays to dwell times. At this point, the bus was about 5 minutes late. The lateness increased as the bus approached and entered the CBD. The bus stopped at most signalized intersections (with particularly long delay at one signal). Toward the end of the route, the bus was nine-minute late.

(iv) An eastbound run departing from Menlo Park at 9:31 am, about two minutes late. The lateness increased quickly. At El Camino and Castro where there was one disabled passenger boarding, it became six-minute late. After that, the bus gradually made up a little time because of good signal progression and light passenger loading (it was following the preceding bus fairly closely). At Santa Clara & 1st Street (in the CBD), the bus overtook the slower bus in front. That was when it began losing significant time. Shortly after overtaking the slower bus, it picked up 75-80 children on a field trip, which took four minutes. Then, the school children alighted from the bus after the next time point, taking another two minutes. The bus was further delayed for another five minutes when the driver left the bus to go to a restaurant for a take-out meal! The bus then encountered traffic congestion toward the last part of the run (including a 90-second wait at one signalized intersection). Finally, the bus arrived at the destination thirteen minutes late.

(v) A westbound run departing from Eastridge at 7:03 am on-time, and remained on time until after the Monroe & Franklin time point (more than one-third of the route). There, it encountered a two-minute delay when trying to turn left onto El Camino due to a large queue of vehicles wanting to turn left. Further downstream, the bus was delayed another two minutes due to a large queue of vehicles waiting to get on San Thomas Expressway. The bus continued to lose time at numerous signalized intersections due to traffic signal delays and frequent stops for passengers. The bus was 11 minutes late toward the end of the route.

(vi) A westbound run departing from Eastridge at 1:44 pm on-time. The bus was late shortly after that, with the lateness increased steadily at each additional time point. The observer did not notice a particular dominant contributing factor for this cumulative lateness, except that the bus made very frequent stops for passengers over the entire route.

(vii) A westbound run departing from Eastridge at 1:34 pm, more or less on time, and remained on-time through the CBD and for two-thirds of the route until El Camino & Castro. There, it was delayed by a large number of school-children boardings at two successive stops (22 boarded at the stop before Castro Street, and 40 more boarded at Castro Street). The bus kept becoming more and more late due to: 20 students alighting at one stop; heavy traffic after El Camino & Page Mill; and frequent stops for passengers.

The bus was seven minutes late toward the end of the route.

The seven runs of Category C collectively imply that:

(a) For Route 22, amplification of initial bus lateness tended to happen more during peak hours than off-peak hours. Amplification of bus lateness also tended to be more common toward the end of the route than during any other part of the route.

(b) The San Jose CBD was the critical bottleneck for Route 22, particularly for eastbound runs, due to: traffic congestion, short city blocks and long delays at signalized intersections, high number of boardings and alightings, handicapped boardings and alightings, and crowded bus.

(c) Contributing factors for Category C lateness on Route 22 included:

- Unusually high number of boardings, the sources of which included: a large group of school children, the preceding bus being early, and bus bunching (in which the front bus decided not to pick up any more passengers).
- Long delays at signalized intersections during peak hours.
- Handicapped boardings and alightings.
- Traffic congestion.
- Driver indiscretions and unscheduled stops (e.g., stopping the bus to buy a meal).

Distribution of Observed Headways on Route 22

Observed service headways and standard deviations on Route 22 during morning and afternoon peak hours are shown in Tables 2.1a and 2.1b for the eastbound and westbound directions, respectively. The tables indicate that standard deviations of observed service headways were large for both eastbound and westbound runs (4.7 and 4.1 minutes, respectively). That is, the standard deviations were more than 40% of the scheduled headway of 10 minutes. This is why bus "bunching" was fairly common on Route 22, as described below.

Bus Bunching on Route 22

As previously mentioned, one contributing factor of Category C lateness was bus bunching. Five ride-along observations were conducted specifically to study bus bunching on Route 22. Each of these observations used three observers riding three successive buses from end to end. Bus bunching was observed in four out of these five ride-along observations. Two of the four observed bus bunching on Route 22 are presented below, one each for westbound and eastbound runs.

Figure 2.3 shows travel profiles of three successive westbound buses, all of which left Eastridge on time beginning at 1:35 pm. Bus 1 was on-time for more than two-thirds of the route before becoming late at El Camino & Castro. From then on, its lateness kept growing (to 7 minutes). Bus 2 began to be late from the first time point, and the lateness kept growing to 8 minutes nearing the end of the route. The observed headways between Bus 1 and bus 2 were larger than 10 minutes for about two-thirds of the route. As tabs 2.1 a and b

fig 2.3

the result, the driver of Bus 3 was either early or on-time at most time points because it did not pick up as many passengers as expected. The observer on Bus 3 noted that many times when Bus 3 was early at time points, the driver would "hold" the bus until the scheduled departure time. Nevertheless, Bus 3 came very close to catching up with Bus 2 after having travelled only less than one-third of the route (at Santa Clara Caltrain Station). Bus 2 and Bus 3 remained "coupled" for at least two-third of the route.

Figure 2.4 shows another observed bus bunching for three eastbound consecutive buses. The figure showed that Bus 1 became late after the mid-way point (Monroe & Franklin), and the lateness kept growing until the end of the route. Bus 2 (which immediately followed Bus 1) was early most of the way, having had fewer than expected passengers to pick up. The driver of Bus 2 did not "hold" the bus at any time points. As a result, potential bunching between these two buses started as they approached the CBD (i.e., during the last one-third of the route), and Bus 2 actually caught up with Bus 1 toward the later part of the route. When the two buses caught up with each other, Bus 1 was way late while Bus 2 was early. Bus 3 (which followed Bus 2) started to become very late during the last one-third of the route, at the time points where Bus 2 was early. Once late, Bus 3 started falling even further behind as it approached the end of the route. This example represents a classic bus bunching cycle -- a late bus was followed by an early bus (when the driver of the latter did not hold the bus), which in turn was followed by another late bus.

fig 2.4

Schedule Adherence of Route 26

Route 26 is also a long bus route; a one-way trip is 26.5 miles long and takes over 1.5 hours. It crosses the VTA's service area in a northwest-to-southeast direction. Unlike Route 22, Route 26 does not go through the San Jose CBD, but lies to the south of the CBD. It has the western terminal at the Lockheed-Martin plant in Sunnyvale and the eastern terminal at the Eastridge shopping center. There were 13 designated time points on the printed timetable.

Route 26 operates with larger service headway than Route 22 -- 20 minutes during peak hours and 30 minutes for the off-peak period. Its daily average ridership was 5,046 riders.

Ride-along observations were conducted on route 26 in March-October 1997. Eight runs were completed during the morning and afternoon peak hours in both directions. Figures 2.5 and 2.6 show schedule-deviation profiles for four eastbound runs and four westbound runs, respectively. The ride-along results indicated that Route 26 had schedule deviation problems during morning and afternoon peak hours. Of the eight runs conducted on Route 26, three runs generally showed good on-time performance, while the other five runs did not.

Analysis of schedule deviations of Route 26 is presented below, using the same three categories of lateness (A, B, and C) as in the Route 22 analysis. Unlike Route 22, both Categories B and C lateness appeared to dominate on Route 26.

fig 2.5

fig 2.6

Category A Lateness

Category A lateness was observed on one out of five late runs. An eastbound run departing from Lockheed Martin at 3:05 pm, about 5 minutes late. The bus gradually and consistently made up all of the lateness toward the end of the route. The driver drove in a hurried manner throughout, pulling away from bus stops as soon as all passengers were on board and some passengers paid fares while the bus was moving. Traffic flow conditions were good, with the bus having mostly good signal progression throughout. Passenger loading was moderate. All these were reasons for the bus being able to make up the 5-minute lateness.

This run suggests that there was slack time in Route 26's timetable to allow a bus under favorable traffic flow and passenger loading conditions to make up a few minute of lateness.

Category B Lateness

Category B lateness was observed for two out of the five late runs, as follows:

(i) An eastbound run departing from Lockheed Martin at 9:02 a.m. on time. The bus became 6-minute late after travelling less than one-quarter of the route at Wolfe & El Camino. Reasons included: a 3-minute delay due to four traffic signals between the Fair Oaks & Tasman and the Wolfe & El Camino time points; and the bus picked up 17 passengers at one stop, nine of whom were disabled. For the next few miles after Wolfe & El Camino, the lateness increased to 7 minutes. After that, the bus steadily made up the lost time due primarily to light traffic flow conditions, light passenger loading, and few stops for traffic signals. However, after the Curtner LRT station, the bus became late again, and it was four minutes late toward the end of the route. The delay over the last part of the route was caused by the driver having to repair the malfunctioning rear door and picking up a disabled passenger.

(ii) A westbound run departing from Eastridge at 7:15 am, about two minutes late. At the next time point (Curtner & Monterey), the lateness increased to 7 minutes due to: a two-minute delay at one traffic signal (the bus got through during the second cycle); traffic congestion (at the intersection of Quimby Road and Tully Road, and near Highway 101); and very frequent stops for passengers. The bus then slightly made up some lost time for several miles until Miller & Bollinger, where the delay increased again to nine minutes. The primary contributing factors were very frequent stops for passengers and at traffic signals. It arrived at the western terminal seven minutes late.

Category C Lateness

Category C lateness was observed on two out of the five late runs, as follows:

(i) A westbound run departing from Eastridge at 5:38 pm, more or less on time. The bus encountered a traffic crash before the first time point, and waited through three cycles of a traffic signal before arriving at Curtner & Monterey four minutes late.

The delay was increased at the Curtner LRT station where the bus picked up a large number of passengers, including one disabled. This plus heavy traffic for the rest of the route made it difficult for the bus to make up time. For the last one-third of the route starting at Westgate, the bus became more late. The lateness kept growing until the bus reached the end of the line about 13 minutes late.

(ii) An eastbound run departing from Lockheed Martin at 8:31 am, about 4 minutes late. The delay increased to six minutes after travelling about one-fourth of the route (at Miller & Bollinger). Two time points later, the lateness grew to 9 minutes. Then, the bus maintained that level of lateness throughout the route. The onboard observer did not notice a dominant factor causing the delay. This was probably a case of the bus being quite late in the beginning, and becoming accumulatively more late throughout the journey because it picked up more passengers than expected along the route.

Close examinations of Categories B and C lateness on Route 26 indicate that long delays at traffic signals, traffic congestion, and larger-than-expected passenger demand were the most common contributing factors. Other contributing factors included: disabled passengers, frequent stops for passengers and at intersections, and accidents/incidents.

Bus Bunching on Route 26

Unlike Route 22, the ride-along observations did not reveal significant bus bunching problems on Route 26. This is reflected by relatively small values of the standard deviation of observed service headways (relative to the scheduled service headways of 20-30 minutes) -- 1.6 minutes for westbound runs and 3.0 minutes for eastbound runs.

Summary of Schedule Adherence Observations

Our observational findings concerning schedule adherence problems of the VTA's busiest bus routes are consistent with evidence in the literature. We found that most buses that were a couple of minutes late at a some point could make up this amount of lateness on their own without external intervention. For bus routes with short service headways such as Route 22, once a bus became late for more than 4 minutes (or 40% of the scheduled headway), it often became even more late downstream. Bus bunching was also a common problem for Route 22 (partly due to the long route and small service headways).

Although Route 26 operated with service headway twice to three times as large as Route 22, contributing factors to its schedule deviation problems were found to be almost similar to those for Route 22, with a few notable differences. First, longer service headways made it easier for late buses to make up the lateness than shorter service headways. Second, larger service headways were associated with a lower probability of amplified bus lateness than smaller headways. Third, bus bunching, which was a common problem for short service headways, did not appear to be so for service headways of at least 20-30 minutes.

VTA's Efforts to Maintain Bus Schedule Adherence

The VTA currently attempts to maximize schedule adherence of its bus system in a number of ways. In some instants, potential problems are known and can be prevented in advance. For example, the VTA usually receives advance notices from municipalities and other agencies about activities that can affect the bus service (e.g., street constructions, special events, road closures, etc.). In such cases, the transit supervisor would first determine the extent of the impacts on buses, and then initiate actions to minimize the negative impacts. Then, the VTA would notify the public of any temporary service changes and the reasons.

More often than not, poor bus on-time performance is a result of less predictable factors (e.g., traffic congestion, unusually high demand, an accident). Although the presence of traffic congestion is often predictable, its extent and impacts on buses is not. To correct schedule deviation problems, the VTA frequently uses the schedule-based holding strategy. Buses are held at time points until scheduled departure times. The VTA does not usually use the headway-based holding strategy, probably because its bus network is largely a modified grid pattern over an expansive service area in which many passengers have to transfer between routes. When it is implemented, only the field supervisor who is present on the route may direct the headway-based holding.

Late buses problems are more common and difficult for the VTA to address. The VTA advises drivers to contact supervisors (via radio communications) if buses become more than five minutes late. The supervisor may then instruct the driver to take actions to improve the schedule adherence or to continue on as usual. An action commonly taken is that the late bus will drop passengers off only but will not pick up new passengers. Whether such an action is implemented often depends on the route's service frequency. If service headway is at least 30 minutes, the supervisor is inclined to instruct the driver to continue on as usual. If service headway is small (10-15 minutes), the supervisor is more likely to recommend such an action. If the supervisor knows that the following bus is also (equally) late, he may instruct the driver of the front late bus not to take any action.

Another strategy that the VTA's supervisor frequently takes with unusually late buses is to insert another bus into the service. The VTA has spare buses located around the service area so that they can be added into service, when needed, in a timely manner. A nearest available vehicle is generally used for this purpose. One scenario is that the late bus will operate in a "drop-off only" mode until the end of the route (or before the end of the route if no more passengers remain), and then return to mid-route (as opposed to the end terminal) to begin its next run. The inserted bus will depart from the end terminal at the originally scheduled departure time of the late bus, and adopts the late bus's timetable.

It is the VTA's policy that the last bus of the day for each route must finish its run at the end terminal no matter how late it is. In case the day's last bus breaks down and no vehicle/driver are available to take over the remaining journey, the bus must continue its run to the end terminal as soon as it is repaired no matter how late it is then. This is important so that riders who depend on the bus service will not be stranded.

TRANSFER COORDINATION AMONG VTA's BUSES

The VTA's bus system has timed transfer operations for routes with service headways of 60 minutes in the evening after 7 pm. Connecting buses typically have layover times at stops designated as transfer points to accommodate timed transfers. Examinations of timetables revealed that such layover times are usually about 6 minutes.

OBSERVATIONS OF PASSENGER WAITING TIMES

Observations of passenger waiting time characteristics were conducted on Route 22 and Route 26 on weekdays in March and November, 1997. Observations were made at a number of selected bus stops in both peak and off-peak periods. As previously mentioned, Route 22 had service headway of 10 minutes all day long. Route 26 had service headways of 20 and 30 minutes during peak and off-peak hours, respectively. Observers were positioned at each selected bus stop to record the time when each passenger arrived at the stop, and the times when each bus arrived and then departed from the stop. In addition, the observers also asked each passenger waiting at the stop whether he/she: had looked up or known the bus timetable before coming to the stop; came to the stop without knowledge of the bus schedule (i.e., arrived randomly); or had just transferred from another bus.

Results of these observations were analyzed and presented below by bus route.

Route 26

For Route 26, a total of 85 passengers (32 eastbound and 53 westbound) were observed. Because service headways for peak and off-peak hours were different, separate analyses were made for the two periods.

Peak Hours

A total of 68 passengers were observed during peak hours. Of these, 36% arrived at stops at random, 34% had looked up or known the bus timetable beforehand, and 30% transferred from another bus. Mean waiting times and standard deviations during peak hours (with 20-minute service headway) for these three groups are:

	Waiting Time (Min.)	
	Mean	S.D.
Random-arriving passengers:	10.18	6.37
Knowing bus arrival time before hand:	10.39	7.00
Transferring from another bus:	7.00	3.39

Off-Peak Hours

A total of 17 passengers were observed during off-peak hours. Of these, 35% arrived at the bus stop at random, 41% looked up or knew the timetable beforehand, and 24% just transferred from another bus.

Mean waiting times and standard deviations during off-peak hours (with 30-minute service headway) for these three groups are:

	Waiting Time (Min.)	
	Mean	S.D.
Random-arriving passengers:	14.67	11.83
Knowing bus arrival time beforehand:	5.29	5.32
Transferring from another bus:	20.50	12.58

Route 22

For Route 22, a total of 28 passengers were observed at a number of bus stops. Of these, nearly two-thirds of passengers (63%) arrived at bus stop at random, 31% looked up or knew the bus timetable beforehand, and only 6% transferred from another bus. Average waiting times at bus stop and standard deviations for these three groups of passengers follow:

	Waiting Time (Min.)	
	Mean	S.D.
Random-arriving passengers:	6.51	3.84
Knowing bus arrival time:	3.44	1.81
Transferring from another bus:	5.00	-

The above results of the two routes collectively indicate that:

(a) When service headway for a bus service is small (ten minutes or less), the majority of passengers tended to ignore the bus timetable and arrive at bus stops at random, with the expectation that waiting time will be relatively small. As service headways increases, the percent of people looking up bus timetables beforehand also increases, while the percent of random arrivals at bus stops decreases, as expected. For service headways of 30 minutes, more people look up bus timetables beforehand than arriving at bus stops at random.

(b) Average waiting time (as well as the standard deviation of waiting time) at bus stops for people who knew bus timetables beforehand was usually smaller that those who came to bus stops at random.

(c) Average waiting time for passengers transferring from other bus lines to Route 26 was found to be 35% of the scheduled service headway during peak hours, and 68% of the scheduled service headway during off-peak hours. For passengers transferring from other bus lines to Route 22, average waiting time was found to be about 50% of the scheduled service headway. This suggests that there is room for improving transfers between different bus lines, particularly during off-peak hours so that average waiting time of transferring passengers at transfer points can be reduced.

CHAPTER THREE

INFORMATION NEEDS OF VTA's BUS RIDERS

Bus riders need good transit information to access the system and make connections. Information needs may depend on whether users are regular or infrequent riders, city size, and bus network. Hall et al (1994) reported that most of calls for information were enquiries about bus itineraries (i.e., how to "best" complete intended trips by bus), and a small percent of calls (about 10%) were for bus timetables. Most regular bus riders might just want the bus number, while infrequent users also wanted information about the street on which the bus operated and the fare.

TRANSIT INFORMATION SYSTEMS IN SANTA CLARA COUNTY

The VTA currently provides information to bus riders via printed timetables and maps, telephone information system, and electronic information system (accessible via personal computers). Printed timetables are posted at some bus stops, as well as being placed on the bus for passengers to take. The other two kinds of transit information systems are described below.

Telephone Information

The VTA's telephone information system provides transit information via Instant Information Line (IIL), as well as trip planning assistance through the Information Center. The first menu option is a choice of information in English or to speak to a service representative. The first choice leads to the IIL; the second choice to the Information Center.

The information consists of fare and timetables for specific bus routes. The caller must first specify the bus route in order to use IIL. If the caller chooses to speak to an operator, the operator will give information about the fare, best route, timetable(s), transfer location, and trip duration. One advantage in speaking to an operator is that the operator may suggest a mode that the caller might have overlooked; for example: to take the light rail system, drive, or carpool instead of taking a bus. Travelers unfamiliar with the available transit service could plan a trip well using the VTA's telephone information system, which offers more details than the electronic information system accessed by personal computers.

Electronic (or Computer-Access) Information

Bus riders familiar with the VTA's bus system may save time using the electronic information system, via the internet. The VTA's web site offers, among other things, information about the fares and schedules for all bus services.

<u>Fare Information</u> The VTA's buses operate on flat fares. Fare information includes fares for various passenger categories (adult, senior citizen, etc.), and various passes that the VTA offers. We

found that bus fare information is concise and easy to understand.

Timetables There are several options to help passengers find the proper bus timetable. Passengers can either directly get the timetable for each route number, or first search a route number by city or location, or first search for a route number by a map of Santa Clara County. A passenger searching for a bus route in a particular city will be shown a complete list of the routes serving that city along with the terminals of each route. A passenger searching for a route number by a map will first be shown a map that includes the entire Santa Clara County (which shows cities, points of interest and possible destinations, streets, all the bus routes, and other transit options color-coded for ease of use). Only the streets on which a bus runs are named on the map. The map covers such a large area that when it is displayed on a computer screen, only city names are readable. The passenger can select an area of the map to be enlarged. General knowledge of the location of an origin or destination is essential when using the map.

Passengers knowing a bus route for which a timetable is needed can go directly to that information without having to search by city or by map. Timetable information is available for weekday, Saturday, and Sunday. Route maps and stop locations are also available. Transfer stops are not provided explicitly, although the user may identify them from the map.

The electronic information system is relatively easy to use if the passenger has general knowledge of the county and the bus system. Those who do not are likely to find it difficult to plan trips using this information system because they are required to identify a specific bus route or to use the map to identify the desired bus route.

Drivers of the VTA's buses are supposed to make stop announcements about upcoming stops and transfer locations. However, our ride-along observations revealed that only some drivers did this, but several did not.

USEFULNESS OF "STATIC" INFORMATION

Evidence in the literature indicates that bus riders have limited ability to plan trips using printed materials (maps and schedule information) alone, and that interactive forms of information systems such as telephone information enhances trip planning ability. A survey in Washington D.C. by Cutler et al (1984) found that two-thirds of transit riders might not have made transit trips without transit telephone information, and that telephone information was most useful to off-peak transit users.

Hall et al (1994) reported that regular transit riders in Southern California gave higher ratings to telephone information service than did infrequent transit users. The authors reported that passengers much preferred telephone as the medium for transmitting transit information, but expressed little interest about information via personal computers.

Bus telephone information systems in the U.S. mostly use hard-copy or computerized information databases. The latter enables relevant transit information (e.g., hours of operation, origins and destinations, cross streets, alternative itineraries, scheduled vehicle arrival times, fares, etc.) to be retrieved more quickly and consistently than the former. Computerized information systems may be provided to callers by human operators or a synthesized voice. Evidence in the literature (e.g., Hall et al, 1994) suggests that callers may register more information about the directions given by a human operator than by a synthesized voice, and that callers tend to perceive that the human operator performs better than a synthesized voice in the clarity and completeness of directions, clarity of speech, and information accuracy.

Electronic information has been implemented in various cities in the U.S., with mixed results. Gildea et al (1996) reported that transit passengers in the San Francisco Bay Area who utilized electronic transit information tended to be students (with easy access to the internet, but limited or no access to automobiles) and higher-income commuters working in downtown San Francisco. About two-thirds of transit riders accessing electronic transit information were first-time users of this information system. Nearly half used it to check scheduled arrival times of buses that they regularly used, and about one-third used the information system to plan new trips.

USEFULNESS OF REAL-TIME INFORMATION

Real-time bus information has not been widely used in the U.S. Passengers' knowledge about bus arrival times in real-time would help to greatly alleviate their anxiety about the bus they are waiting for when it is running late or when passengers have to make connections with another bus. Further, the ability of riders to utilize the time spent in waiting for a bus is limited, and riders usually overestimate waiting times at bus stops when buses do not run on-time.

In addition to real-time bus arrivals, real-time information about location and status of buses and expected running time would also be desirable to most bus riders. Hickman et al (1995) described three basic elements of real-time information: information content (e.g., expected bus arrival time, bus location, expected running time); location of information display (at bus stops, onboard buses); and quality of information. Cowell et al (1988) studied a brief demonstration project in England, in which real-time bus arrival times were displayed at bus stops. The authors reported that 87% of passengers considered such real-time information "useful", but there was no evidence of increased bus ridership during a brief demonstration period.

INFORMATION NEEDS OF VTA's BUS RIDERS

We conducted a survey to determine information needs of the VTA's bus riders. Riders on four bus routes in Santa Clara County participated in the survey: Routes 22, 25, 26, and 70. These routes were selected because of their very high ridership levels (compared with other VTA's bus routes), and because they collectively represent a continuous range of service headways from about 10 to 30 minutes. Headways for Routes 22, 70, 25, and 26 were 10, 15-20, 20-30, and 20-30 minutes, respectively.

We distributed questionnaires to riders onboard buses, to be completed and returned either on the spot or by mail. The questionnaire consisted of two major sections. The first section asked about rider characteristics: gender, frequency of bus use per week, trip purpose, and time of trip. The second section asked about passengers' perceptions of usefulness of several kinds of currently available (i.e., static) and real-time information, as well as information display mediums as follows:

Static Information Posted at Bus Stops

- Bus timetables posted at all bus stops.
- Fares posted at bus stops.
- Route maps posted at bus stops showing connecting routes and transfer locations.

Static Information Via Telephone or Personal Computers

- Bus timetables via telephone and/or computer.
- Bus fares via from telephone and/or computer.
- Route maps showing connecting routes and transfer points via personal computers.
- Connecting routes and transfer points via telephone.

In-Vehicle Information

- In-vehicle stop announcement.
- In-vehicle announcement of transfer points as the bus

approaches each.

- In-vehicle announcement of departure times of connecting buses as the bus approaches a transfer stop.
- Route maps posted inside buses showing connecting routes and transfer points.

Real-Time Information

- Real-time arrival times of the desired bus displayed at bus stops.
- Real-time locations along the route of the desired bus displayed at bus stops.

Survey respondents were asked to rank information items as very useful, somewhat useful, or not useful. The questionnaires were distributed in early May on a Monday and Thursday, during morning peak hours until mid-afternoon. A total of 291 questionnaires were distributed; 110 were completed and returned (a response rate of 37.8%). Response rates for the four bus routes were similar.

The survey returns were analyzed and the results follow.

Respondents' Characteristics

Characteristics of the respondents are summarized below:

Gender 55% of the respondents were females, and 45% males.

Frequency of Bus Use 81% of respondents used buses over three times a week, 12% one to three times a week, and 7% infrequently.

Trip Purposes 51% of the respondents used buses for work, 37%

for school, 33% for shopping, and 23% for other purposes. Because the respondents were asked to check as many boxes as applicable, the total percent of all trip purposes exceeds 100%.

Time of Trips 58% of the respondent made trips by bus at 6-9 am, 40% between 9 am and 3 pm, 43% at 3-7 pm, and 14% after 7 pm. Because the respondents were asked to check as many boxes as applicable, the total percent of all times of day exceeds 100%.

Knowledge of Bus Timetable On the day of the survey, 31% of the respondents had looked up bus timetables before coming to the bus stop, 57% knew the bus timetable from experience, and 12% arrived at the bus stop at random. Closer examination of the data revealed that for work trips, almost all of the respondents (98%) either had looked up the bus timetable or knew the timetable from experience beforehand.

Transferred Passengers On the survey day, 23% of respondents transferred from one bus to another to get to destinations.

Information Needs

Regular Bus Riders

Of the 110 respondents, 102 used the bus at least once a week, and these riders are called regular bus riders. The rank-ordering of the 13 information items by these riders indicates that they perceived the following information items to be the most useful. Rank 1 indicates that the information item was perceived to be very useful by the largest number of respondents, while a rank with the highest numerical value indicates that the information item was perceived to be very useful by the least number of people. The parenthesized percent is the proportion of the respondents indicating that the information item was or would be "very useful" to them.

Rank 1: Real-time displays of bus arrival times at bus stops (80%).
Rank 2: Bus timetables posted at all bus stops (78%).
Rank 3: Route maps showing connecting routes and transfer points posted at bus stops (73%).
Rank 4: Route maps showing connecting routes and transfer points posted inside the bus (62%).
Rank 5: Real-time displays of bus locations at bus stops (57%).

On the other hand, regular bus riders considered the following five items as being less important:

Rank 9: Bus timetables via telephone and/or computer (45%).
Rank 10: Bus fares posted at bus stops (43%).
Rank 11: Route maps showing connecting routes and transfer points via computers (42%).
Rank 12: Connecting routes, transfer points via telephone (38%).
Rank 13: Bus fares via telephone and/or computer (32%).

The above survey results imply that:

(a) Regular bus riders expressed very high enthusiasm about having real-time displays of bus arrival times at bus stops, more so than any other information items. These riders were also enthusiastic about having real-time displays of bus locations at bus stops, although to a lesser extent than real-time bus arrival times.

(b) Regular bus riders highly valued conventional bus timetables and route maps posted at bus stops and inside the bus, more so than having this information via telephone or personal computers. A plausible explanation is that regular riders considered such information via telephone and computers would require too much forethought and efforts to use, particularly when they already had made decisions to use the bus.

(c) Regular bus riders generally expressed little need for fare information. Please note that the VTA has flat fares for its bus system, which might have made fare information even less important for most regular riders.

Infrequent Bus Riders

Only 8 out of 110 respondents used buses infrequently (i.e., less than once per week). Even though eight infrequent bus riders is a very small sample size, their responses appear to differ from the those of regular riders and may help to shed some light on information needs of "choice" riders and possibly non-bus users.

The five most favored items among infrequent bus riders are:

Rank 1: Real-time displays of bus arrival times at bus stops (63%).

Rank 2: Route maps showing connecting routes and transfer points via personal computers (63%).

Rank 3: In-vehicle stop announcement (50%).

Rank 4: Bus timetables via telephone and/or computer (50%).

Rank 5: Real-time displays of bus locations at bus stops (50%).

The above responses of infrequent bus riders imply that:

(a) Like regular bus riders, infrequent bus riders also highly valued real-time displays of bus arrival times and real-time displays of bus locations at bus stops, particularly the former.

(b) Infrequent bus riders highly valued bus timetables and route maps via telephone and personal computers more than regular riders. A plausible explanation is that infrequent riders may be more likely to use such information to pre-plan trips (at home). This finding is supported by the fact that, unlike regular bus riders, infrequent riders perceived timetables and route maps posted at bus stops to be less important.

(d) Like regular bus riders, infrequent bus riders did not perceive fare information to be all that important.

Perceptions Between Males and Females

Comparison of the responses between male and female respondents revealed the following:

(a) Female riders valued in-vehicle announcements (upcoming bus stop, transfer stop, and departure time of connecting routes) much more than male riders (64% females versus 39% males perceived these to be "very useful"). Possible explanations are: female riders were more concerned about getting off the bus at wrong stops or not making connections with another bus; and female riders were more likely to be accompanied by young children, and thus were more concerned about alighting at wrong stops and mis-connections.

(b) Male riders valued maps of connecting routes and transfer points via telephone or personal computers more than female riders (46% males versus 31% of females). Both males and females equally valued bus timetables via telephones or personal computers. With the VTA's current transit information system, computer-access maps are more difficult to use than computer-access bus timetables. Thus, these findings may imply that more male riders probably had "comfort level" than females in using personal computers to explore transit information.

(c) Both male and female riders generally did not regard fare information to be very important.

Perceptions Between Work Trips and Non-Work Trips

There was no appreciable difference in the perceptions of information needs between work and non-work trips.

Perceptions Between Peak and Off-Peak Bus Riders

There was no appreciable difference in transit information needs between peak and off-peak bus users.

Perceptions of Riders on Different Bus Routes

The four surveyed bus routes differed in service headway: short headway (10 minutes or less), medium headway (11-20 minutes), and long headway (21-30 minutes). However, there was no appreciable difference in information needs of riders among these bus routes.

STRATEGY FOR REAL-TIME TRANSIT INFORMATION SYSTEM

There appeared to be diverse information needs among bus riders in Santa Clara County. Although transit information via telephone and personal computer were generally valued by many infrequent/unfamiliar riders, most regular bus riders would rather see timetables and maps posted at bus stops and inside the bus.

Most bus riders in Santa Clara County were very enthusiastic about real-time displays of bus arrival times at bus stops, and to a less extent, real-time displays of bus locations bus stops. Such real-time information would serve many purposes. First, it would help to reduce passenger anxiety when the bus they are waiting for is running late. Second, displays of arrival times of many successive buses at bus stops would enable waiting passengers to see the existence of bus bunching (if any), so that they might decide whether to wait for a less crowded bus if one would be due soon or to board the first crowded bus. Third, this real-time information might enable passengers to make better use of their time that would otherwise be spent in waiting at bus stops. Finally, it would enable riders to decide to continue waiting for a bus or to use an alternative mode for that trip.

When might real-time bus arrival information be particularly desirable? Bus riders are likely to benefit most from real-time displays of bus arrival information at bus stops for bus routes with high service frequencies and high passenger demand. This is because schedule adherence is usually more difficult to achieve for such bus routes in the face of incessant urban traffic congestion, traffic incidents, and stochastic passenger demand. However, real-time bus arrival information is not and cannot be a substitute for bus service reliability. Riders are not likely to be entirely happy with real-time bus arrival information if bus service reliability is constantly poor. Therefore, transit agencies should utilize AVL to improve bus service reliability first, then attempt to improve service quality further by providing real-time bus arrival information to passengers.

For bus routes with low service frequencies and lower passenger demand, service reliability may be more easily achieved. Besides, passengers tend to look up bus timetables beforehand (as opposed to arriving at bus stops at random) when service headways are large. All these may make displays of real-time bus arrival information at bus stops less important for low-frequency bus routes than for high-frequency bus routes.

Methods of Providing Real-Time Bus Arrival Information

In providing real-time bus arrival information to passengers at bus stops, AVL information must be transmitted to bus-stop displays. This may be accomplished by:

o Centralized Control As soon as the control center receives real-time positions of a bus from AVL, it calculates and updates expected arrival time of the bus at each stop. This information may be transmitted to bus-stop displays by telecommunication lines or radio paging. Of the two means, radio paging may be less expensive because it does not require fixed infrastructure and installation of communication lines (underneath roadway surface).

- o <u>Distributed Control</u> As an alternative to centralized control, real-time bus arrival information may be transmitted directly from individual buses to bus-stop displays. This kind of a distributed control would require installing controllers at bus stops and a computer onboard each bus. AVL would provide exact bus positions to the onboard computer, which would enable calculations and updates of bus running time and arrival time at each bus stop. The onboard computer then transmits this information directly to bus-stop controllers using radio or other forms of wireless communication means. Unlike a centralized control, communication cost of a distributed system may not be sensitive to the number of bus-top displays.

CHAPTER FOUR

CONTROL STRATEGIES FOR BUS SCHEDULE ADHERENCE AND TRANSFER COORDINATION

Bus on-time performance usually refers to how closely a bus adheres to its timetable at various time points along the route. Bus timetables publish either vehicle arrival/departure times at time points or service frequencies (or headways). An example for the latter is "the bus arrives every 10 minutes".

Factors affecting on-time performance of buses are stochastic variations in vehicle travel times between stops, passenger demand (boarding and alighting), dwell times at stops, and driver behaviors. Once a bus starts to deviate from its schedule and if this deviation is not corrected, the deviation may escalate. Escalation of schedule deviation by one bus can eventually lead to bus "bunching" (successive buses end up traveling in a platoon). Bunching is a frustrating problem for passengers because a bus for which they are waiting is usually way behind schedule, and when a bus arrives it is often too full to pick up more passenger.

There is ample evidence in the literature that the number of traffic signals along the route is the single most important factor affecting variations in bus travel time between stops. Other factors include: traffic congestion, traffic incidents, and driver behaviors.

Unusually light or heavy passenger demand can result in unexpected dwell times at bus stops, causing the bus to deviate from its schedule. Wheelchair and handicapped passengers usually require extra time at bus stops, thus increasing bus dwell times.

CONTROL STRATEGIES FOR SCHEDULE ADHERENCE

Strategies for improving schedule adherence of fixed-route bus services may be preventative or corrective measures. Preventative strategies attempts to prevent significant deviations from timetables. Corrective strategies attempts to correct schedule deviations and their impacts when they occur. Various strategies for improving bus schedule adherence are presented below, together with how real-time information from AVL may help to increase the effectiveness of these strategies.

Developing Realistic Bus Timetables

Bus timetables should reflect prevailing traffic conditions, passenger demand, and surrounding environment, particularly the inherent variations (stochastic nature) in these factors. A bus timetable reflect average vehicle run time, taking into consideration factors such as passenger and traffic flow variations by time of day, direction of travel, day of week, and section of route. It is desirable to include some layover time at terminal points to allow for driver breaks and vehicle refueling, as well as for late buses to make up lost time.

Real-time information from AVL has the potential to help the transit agency to develop realistic bus timetables. AVL provides detailed accounts of locations and status of all buses throughout the day. Therefore, more and better-quality data would be available for the agency in a timely manner to use as the input in revising timetables. At the present time, transit agencies rely on information obtained from a number of sources (e.g., drivers, supervisors, ride checking, and limited traffic surveys) as input for schedule revisions every quarterly or bi-annually. Real-time information enables transit agencies to refine bus schedules as needed.

Bus Priority Treatments

Bus priority treatments could help to improve bus schedule adherence through increasing bus travel speed and minimizing travel time variations in traffic congestion and on streets with a large number of closely-spaced traffic lights. Two bus priority strategies are describe below -- traffic signal timing and exclusive bus lanes.

Traffic Signal Timing

Our ride-along observations of VTA's bus routes revealed that longer-than-expected delays due to traffic signals occurred frequently on city streets. Closely-spaced traffic signals near and within the San Jose CBD, as well as nd multiple phases and long cycles of traffic signals, are primary causes. For example, the intersection of El Camino Real and San Thomas Expressway (both of which are major roads) was observed to have a cycle length of 3 minutes.

Signal timing can be set to give priorities to buses. Many priority options with varying degrees of priorities for buses may be considered, as followed:

o Fixed Timing Plans. Skabardonis (1998) suggested that fixed signal timing plans can be set to favor bus movements at intersections. This involves adjusting offset between successive signals to account for lower bus speed and mid-block dwell time, as well as alternating bus stop locations between the near side and the far side of successive intersections.

o Signal Timing With Phase Extension for Buses. A low degree of signal per-emption that includes "phase extension" for buses can provide priorities for bus movements at intersections. This involves having an approaching bus extends the green phase sufficient for the bus to go through the intersection during that phase. This option requires bus stops to be located on the far side (as opposed to the near side) of the intersection. (Skabardonis, 1998) suggested that this limited signal pre-emption could be accomplished by using strobe light emitters on the bus and special light detectors at the signal, radio control, or special loop detectors that could recognize buses. The author believed that AVL would be even more beneficial than these methods, because AVL interfacing with the signal control system would permit anticipation of pre-emption needs and real-time signal control adjustment from the traffic control center.

o Signal Pre-Emption for Late Buses. This option involves pre-empting traffic signals only for buses that are running very late (by more than a pre-specified amount of time). This would help to minimize adverse impacts on cross-street traffic. A bus (that is pre-determined to be late) approaching a traffic signal during the red phase would activate the green phase. When a late bus approaches a traffic signal during the green phase, it would lengthen the green phase sufficiently to proceed through the intersection unhindered.

This kind of signal pre-emption would require AVL that provides real-time locations and status of buses as well as having the ability to determine whether a bus is late (which requires high frequency of vehicle polling). Activation or lengthening of a green phase can be accomplished via a short-range communication link between the bus and the traffic signal (decentralized control) or via the traffic control center (centralized control).

This signal preemption option should not be used until a bus' lateness becomes greater than some pre-specified value. Our observations of VTA's buses revealed that most buses were able to make up lateness on the order of 2-3 minutes on their own, without any external intervention.

Interviews with personnel of the VTA indicated that once AVL installation on buses is completed, the VTA would consider some form of signal peremption for buses to improve schedule adherence of certain bus routes.

Exclusive Bus or High Occupancy Vehicle (HOV) Lanes

Exclusive bus or HOV lanes enable buses to bypass traffic gridlock on streets and freeways, and thus reducing travel time as well as variations in travel time between stops. The primary disadvantage of exclusive bus lanes on city streets is that they generally take one lane (per direction) away from general traffic, which could considerably worsen traffic congestion on the street. High-occupancy-vehicle lanes on many freeways can be provided without taking existing lanes from general traffic.

Vehicle Holding

Holding buses at well-selected control points can help to maintain desired separations between successive buses. This strategy has been commonly used to address poor schedule adherence of buses. The following options are available:

Schedule-Based Holding

When it is deemed that adherence to the timetable is more important than maintaining constant service headway, bus departures from control points can be held to coincide with published departure times. Common reasons for adopting a schedule-based holding include: buses are scheduled to meet with other buses at some transfer points to serve connecting passengers; arrival times of buses have been carefully planned to balance passenger loads among successive buses; and scheduled service headways are not constant. Liu (1995) reported that for the schedule-based holding option, desirable locations for control points were stops where the number of downstream passengers waiting to board the bus was dominant over the number of passengers already onboard the bus.

Real-time information from AVL is ideal for implementing this kind of holding. Without real-time information about locations and status of all buses, dispatchers have to rely on driver reporting late (or early) buses (which may not always happen). Experience of using AVL in London (Wileman 1995, and Atkins 1994) indicated that there was some improvement in on-time performance through use of AVL for low-frequency bus routes. For high-frequency bus routes, traffic congestion was such a dominant factor of schedule deviation that the use of AVL resulted in little improvement in bus on-time performance.

Headway-Based Holding

Headway-based holding is preferred when headway adherence is deemed more important than adherence to the timetable. This is often the case when buses operate with high frequencies (every ten minutes or less) or when the timetable state service frequencies (instead of bus arrival/departure times). For bus routes with high service frequencies, most passengers may not pay much attention to timetables. They are likely to arrive at bus stops at random, believing that average waiting times for a bus will be small.

With either schedule or headway holding, the current practice is to hold early buses at control points until scheduled departure time (or departure time advised by field supervisors). Thus, vehicle holding directly affects early buses by preserving a desired headway between successive buses. It indirectly affects late buses to the extent that an early bus in front is being held to reduce the separation between it and the late bus behind. In doing so, it may prevent the late bus from falling even further behind.

The effectiveness of vehicle holding may diminish as the "controlled" bus moves further downstream from the control point, and may again begin to deviate from schedule. This suggests that many control points may be needed along a bus route. An optimal number of control points represents a tradeoff between the delay incurred by passengers already onboard the held bus and passengers waiting at downstream bus stops. By maintaining a desired separation between successive buses, vehicle holding will reduce passenger waiting times at downstream stops. However, whenever a bus is held at a stop, passengers already onboard the bus incur extra delay. Further, too many control points also invariably increase journey time for the controlled bus. A control point located in the middle of the route, after a large number of passengers have already boarded, would delay the largest number of on-board passengers. On the other hand, this location would be where service headway variations are likely to be the most extreme, and waiting times for passengers at downstream stops would be minimized. As a general rule, an optimal location for a control point is just before the stop that has the maximum number of passengers onboard. Such a stop would balance the benefit accrued to downstream passengers with delays incurred by passengers already onboard the bus.

Evidence in the literature indicates that field supervisors sometimes were reluctant to hold buses, and sometimes did not have essential information to base their decisions on. Real-time information about locations and status of buses from AVL would address this lack of information.

In some prior vehicle holding implementations, the benefit from vehicle holding remained even after the strategy ended. This suggests that drivers might have paid more attention to on-time performance when knowing that their performance was being scrutinized by supervisors.

"Pre-Fol" Vehicle Holding

When bus bunching is a commonly occurring problem along the route (e.g., VTA's Route 22), a special vehicle holding option, the "pre-fol" control, may be desirable (Blume, 1980). This involves holding a bus at a control point, by taking into consideration the headway to the preceding bus, headway to the following bus, amount of time the previous bus was held, and the proportion of passengers delayed. The amount of time that a bus is held is estimated from:

$$X_i = \max [\ 0\ ,\ 1/2(\ H_{i+1} - H_i - (b/(1-b))H_i + X_{i-1}\ )\ ]$$

where X_i = amount of time to hold the bus

H_i = previous headway

H_{i+1} = following headway

X_{i-1} = amount previous bus was held

b = proportion of passengers delayed

When the estimated amount of time to hold the bus is zero or negative, no vehicle holding is necessary. The proportion of passengers being delayed is a policy-based parameter. The amount of time the previous vehicle was held is important so that buses would not be continually pushed back, perhaps to a point where the entire day's schedule is disturbed in an effort to achieve an even headway distribution.

The "pre-fol" holding requires information about locations and status of all buses operating on the route. Therefore, it can greatly benefit from use of AVL. The magnitude of headway correlation between successive buses influences the benefit of this holding option, with maximum benefit occurs when the headways are perfectly negatively correlated (i.e., a short headway was always followed by long headway, with equal deviations from the scheduled headway).

The potential benefits of real-time information from AVL on vehicle holding are tremendous. This is because the need for, and the kinds of, vehicle holding to be implemented may vary by time-of-day, direction of travel, patterns of boarding/alighting along the route, number of control points, and schedule deviations of successive buses. Senevirante (1990) reported that vehicle holding worked best if control points changed from trip to trip, depending on prevailing traffic conditions and patterns of boarding/alighting along the route, and schedule deviations of other buses. Abkowitz and Tozzi (1986) found that headway-based holding worked best for routes in which there were relatively low numbers of on-board passengers at the early stops, most of the boarding passengers doing so in the middle of the route, and then alighting at the end of the route. An example of such a route would be an afternoon peak run that begins before the CBD and ends in the suburbs.

Without AVL, good input data for sound vehicle holding decision would be difficult and expensive to obtain.

Supervisory Interventions

Transit supervisors are often called upon to solve a multitude of bus service reliability problems. Field supervisors may direct drivers to take certain actions to address the serious problems of late buses and/or bus bunching. Field supervision may be foot or mobile supervision. Foot supervision is mostly seen within the CBD, whereas mobile supervision has a greater mobility and can cover more routes and areas than foot supervision. Supervisors may direct drivers to pursue any of the following options to try to correct bus schedule deviation problems.

Changing Speed

A bus that is behind a late bus may slow down considerably to increase the separation between the two buses. This would enable the following bus to pick up its share of passengers and lower the probability of bunching. The field supervisor or the driver of the following bus needs information regarding the location and speed of the bus in front in order to appropriately adjust speed of the following bus. Without such information, the driver of the following bus has no way of knowing about an impending bunching with the bus in front until his/her bus actually catches up with the bus in front.

AVL would provide necessary real-time information for this option. Moreover, an AVL system with an onboard driver display unit can show a headway between successive buses as well as the magnitude of schedule deviation of buses. This would enable bus drivers to slow down or speed up as appropriate.

Leapfrog

When bus bunching occurs or is imminent, the field supervisor may direct the driver of the following bus to "leapfrog" (overtake) the front bus. This can serve a number of purposes. First, the overtaking bus can put some distance between itself the overtaken bus in order to immediately reduce the degree of bunching. Second, if the overtaking bus is relatively empty and the overtaken bus is crowded, the former would be able to pick up passengers at downstream stops. This could help to prevent the overtaken bus from falling further behind, and to reduce waiting times of passengers waiting at downstream stops.

Skipping Stops

When bunching is imminent, the field supervisor may direct one of the buses to skip stops to create an immediate separation between the two buses. Skipping stops invariably makes passengers waiting at skipped stops unhappy, particularly when they do not know when another bus will arrive. This is where real-time displays of bus arrivals at bus stops would be helpful to waiting passengers.

"Closed Door" Operation

For a very late and crowded bus, the field supervisor may direct the driver to operate “closed door”. That is, the bus will let passengers off but will not board any new passengers. This is in order to reduce dwell times at stops, create balanced loading between this bus and another closely-following bus, and create a separation between buses in a bunching situation. As a practical matter, the driver of a bus operating “closed door” may let passengers off at some distance before the bus stop to avoid conflicts with passengers waiting to board the bus. The “closed door” operation can be confusing and frustrating to waiting passengers even when the field supervisor present at the stop may inform waiting passengers that another bus will arrive momentarily.

Short-Turning

Evidence from our ride-along observations of Route 22 revealed that bus bunching, and very late buses, tended to occur toward the later part of the route. The field supervisory may instruct the late bus to turn around before reaching the end terminal and to start the return trip from that point. This could help to create a significant separation between buses in the bunching. Passengers on the short-turned bus, if any, need to be transferred to another closely-following bus.

At the present time, decisions to implement a supervisory intervention generally depend on field supervisor's judgment and whatever information available to the supervisor at that instant. Real-time information from AVL could play an important role in facilitating these supervisory measures. It could help to improve the effectiveness of supervisory measures because it enables dispatchers and supervisors to learn (or anticipate) about any problems automatically (as opposed to having problems reported by drivers, which may not always happen). When there is real-time information continuously available about locations and status of all buses, it would be far easier for supervisors to make good decisions on appropriate control measures to correct the prevailing problems. AVL could also help to relieve the workload of supervisors because real-time decisions could be made at, and communicated to bus drivers from, the control center instead. Wileman (1995) reported that AVL used in conjunction with mobile supervision could result in maximum benefits because face-to-face contact between drivers and supervisors help to: (a) personalize communications between the two; and (b) further influence drivers to pay particular attention to on-time performance.

There have been successful experiments with using real-time information to improve bus operations. In Zurich, Switzerland, real-time information was used to allow dispatchers to issue control commands at each bus stop, essentially making every stop into a control point. The result was that on-time performance of that bus system improved. Nevertheless, some transit professionals (e.g., Osuna et al, 1972) suggested that strategies making use of real-time information should be implemented only after service had deteriorated until or past some threshold value, but not in anticipation of a problem that is yet to occur. Their rationale was that some schedule/headway deviations could correct themselves, and premature intervention only added extra delay to bus journey.

Inserting Additional Buses

When a bus is running very late and no corrective measure is effective, it will fall further behind as it encounters higher-then-expected passengers. When an unforeseen incident occurs (e.g., vehicle breakdown, traffic accident, road construction, emergency road closure, etc.), considerable delay occurs suddenly. In these and other similar situations, an additional bus can be dispatched to help restore the schedule deviation of the late bus. The added bus should be inserted in front of the late bus to pick up passengers, so that the late bus can make up time by letting passengers off only. The inserted bus may finish its run when the late bus gets back on schedule again or at the end of the route.

Changing Route Structure

Evidence in the literature indicates that buses operating on very long routes are susceptible to cumulative schedule deviations (that could lead to poor on-time performance) than on shorter routes. Levinson (1991) suggested that a round trip for buses should be kept under 25 miles long or two hours in duration. Many bus routes with of the VTA system are much longer than this limit.

One remedy for very long bus routes with incessant poor schedule adherence problem is to break the bus route into two segments. This remedy is desirable for long routes passing through a CBD (or a high demand or congested urban area), with terminals far beyond both sides of the CBD. When dividing the original route into two segments, one segment should begin on one side of the CBD (say, the west side) and terminate just after the CBD on the east side. The other segment would mirror the first, beginning on the east side of the CBD and terminating on the west side of the CBD.

Driver Monitoring

Many prior studies (e.g., Englisher, 1984) reported that bus drivers often paid greater attention to being on-time and achieved better on-time performance during a driver monitoring program. Further, such improvement continued to be observed even after the driver monitoring was removed.

The current practice in driver monitoring is done by field supervisors. Therefore, comprehensive monitoring is inexpensive and difficult. Real-time information from AVL would be ideal because all buses would be monitored at all time, everywhere in the network.

Driver Incentives

The Houston Metro implemented a driver incentive program in 1989, as part of a labor contract. This incentive program specified several driver performance goals (which included on-time performance, passenger complaints, accidents). Rewards, as a certain percent of basic salaries, were given to drivers who were able to achieved these goals. Any improvement goals that could not be made clear to drivers in terms of the impacts of driver behaviors/actions on system performance were excluded. The rationale was that drivers must know that they could affect the system in order to attempt improvements. The Houston Metro offered cash rewards of 0.75%, 0.56%, and 0.37% of salaries if drivers achieved 90%, 89%, and 88% systemwide on-time performance, respectively.

Such a driver incentive program, which equates cash rewards to the percent of on-time performance, requires accurate and thorough measurements of driver on-time performance. A lesson learned in the Houston Metro program during the initial period was that supervisors checked on-time performance mostly in the downtown area but not in suburbs. As a result, the on-time performance goal was routinely met by most drivers in the downtown area but not in suburbs where poor on-time performance persisted. The Houston Metro, consequently, altered the measurement to cover systemwide on-time performance.

AVL would automatically provide accurate, consistent, and thorough on-time performance of all drivers and buses. Such real-time information is likely to be more detailed, of better quality, and less expensive than measurements made by field supervisors.

Comprehensive Team Approach

In 1989, the Southern California Rapid Transit District (SCRTD) implemented an innovative program to improve on-time performance of bus lines that had chronic reliability problems. This emphasized teamwork among management and line personnel. The program involved the following steps:

1. Target bus routes were selected through ranking of all bus route by load factor, and the most crowded buses were given priorities for treatments. Other considerations included: passenger complaints, and incidence of late buses.

2. Next, the agency publicized the program among drivers and other office and line staff. After collecting some baseline data, a meeting was convened among supervisors, operations personnel, and planning personnel to discuss problems evident from customer surveys and complaints, driver surveys, point checking, and other sources.

3. Next, for each target bus route, drivers were interviewed to get their input on possible improvements and to establish a teamwork.

4. Next, improvement strategies were devised and tested for

each line, primarily during peak hours. Supervisory presence on each line was established wherein supervisors were given flexibility in initiating and testing any new ideas. Strategies tested included: supervisors' field monitoring of on-time performance; tweaking bus timetables to better reflect current operating realities; and vehicle holding.

5. Then, follow-up team meetings were convened to discuss the results of implemented actions, and to select promising strategies for each line.

6. Lastly, promising improvement measures were implemented on each bus line, and supervisory presence on the line was also maintained.

CONTROL STRATEGIES FOR BUS TRANSFER COORDINATION

The purpose of bus timed transfer is to set up a coordinated scheduling and operating procedure among connecting bus routes at designated transfer points to enable passengers to transfer between buses with minimum delays. The most basic form of bus timed transfer is between two bus routes, in which both are scheduled to arrive at the transfer point at the same time. Another simple bus timed transfer is a "line-up" operation, in which buses of different routes are lined up at the transfer point, typically on the last runs of the day to assure that passengers are not stranded.

A more complex timed transfer is a pulse system, in which many buses converge on a transfer terminal at the same time, and then depart in different directions. In this case, the transfer terminal must have enough space to hold pulsing buses on or off street. The most complex pulse system involves many connecting bus routes and many transfer points within the bus network.

Schedule adherence of all connecting buses is a critical condition for the success of all timed transfer operations.

Current practices in bus timed transfer may or may not involve (radio) communications between drivers of connecting buses. Without communications between drivers, connecting buses are scheduled to arrive at the transfer point at the same time and the bus arriving first would wait (blindly) for the other bus (or buses). Poor schedule adherence by any of these buses can cause all connecting buses to be off schedule. Communications between drivers of connecting buses (directly or via a dispatcher) about status of buses make it possible for the driver of the early bus to decide whether he/she should wait at the transfer point for the other bus if the latter happens to be late.

As in bus schedule adherence, the stochastic natures of traffic conditions, passenger demand, dwell times at stops, and driving characteristics present challenges in designing and implementing bus timed transfer. Timed transfer strategies are generally based on optimizing an objective function that considers both transfer and non-transfer costs. Transfer costs include vehicle and passenger waiting times in transfer terminal, and the cost of mis-connections. Non-transfer costs include vehicle running cost, delay cost to passengers already onboard the buses, and waiting times for passengers at bus stops.

When bus routes have high passenger demand and provide very frequent services, timed transfer may not be necessary or economical. In this case, service headways for individual bus routes can be optimized independently.

When passenger demand is low and/or service headways are large, timed transfer among connecting bus routes is desirable. Strategies to help accomplish this include the following:

Developing Coordinated Bus Timetables

Perhaps the most common strategy currently used by most transit agencies is to pre-plan coordinated schedules for all connecting bus routes, with a view to minimizing waiting times for transferring passengers at transfer terminals. This involves scheduling all buses to meet at a designated transfer point at the same time (or nearly the same time). Coordinated bus scheduling may require adding small amounts of slack times into schedules of individual bus routes. For example, well planned layover times at a transfer point can accommodate some schedule deviations of connecting buses. Layover times for this purpose may be on the order of 5-6 minutes. Optimal slack time for bus timed transfer can be determined based on a tradeoff between the cost of mis-connections and the cost of vehicle dispatching delays.

Adding slack times into bus schedules is desirable and feasible when uncertainties in bus arrivals are low and service headways are large. For a given service headway, as the variation in arrival times increases, the slack time should first increase and then decline to zero as the arrival-time variance increases further (i.e., slack time becomes uneconomical).

Two options for developing coordinated bus schedules are:

- Coordinated Scheduling With One Common Headway. This involves scheduling all connecting bus routes to have the same common service headway. This strategy is preferred when service headways of connecting bus routes are large and variances of headways and travel times are relatively small.
- Coordinated Scheduling With Integer Multiple of Basic Headway Cycle. A basic headway cycle is the minimum service headway among all connecting bus routes. Service headways of all connecting routes are set as some integer multiples of the basic headway cycle. This option is preferred when at least some service headways are large and variances of headways and travel times are also large.

Vehicle Holding Without Communications Among Drivers

Even with pre-planned coordinated bus schedules, some buses will arrive at the transfer terminal before others, and some buses will invariably be late. A number of vehicle holding options can address the problem of late buses in the absence of communications among drivers of connecting buses, as follows:

A. Connecting buses are scheduled to arrive at a transfer point at the same time, and they do not wait for each other.

B. Connecting buses are scheduled to arrive at a transfer point at the same time, and each incoming bus is held until all buses have arrived.

C. Connecting buses are scheduled to arrive at a transfer point at the same time, and the larger-headway bus is held until the smaller-headway bus arrives (but not vice versa).

D. Connecting buses are scheduled to arrive at a transfer point at the same time, and buses are held until some pre-specified time if all buses have not arrived.

E. Connecting buses are scheduled to arrive at a transfer point at the same time, and the early bus may be dispatched as soon as it is ready if there are considerable uncertainties regarding arrival times of the other buses. This decision should be made by a supervisor present at the transfer point. This option is desirable when the early bus has a large number of passengers and/or the late bus is known to generally carry very few transferring passengers.

Option (B) is likely to result in long waits for passengers if one of the connecting buses is very late. Option (E), with intervention by the field supervisor, can help to address this problem.

Without knowing status of late buses, the choice among the above holding options must be pre-specified and then strictly followed by all drivers. One disadvantage of a pre-specified option is that any one option selected is not likely to work well under all circumstances.

Vehicle Holding With Driver Communications

Vehicle holding would be more effective if drivers of late buses can communicate the vehicle status to drivers of other connecting buses or to the dispatcher (via radio). In this option, drivers may be asked to radio the dispatcher whenever their buses are late by some critical amount. The dispatcher can then make decision about holding the bus that has reached the transfer point, and then communicate this decision to the driver. Alternatively, the information about the status of the late bus can be conveyed to an on-street supervisor who then makes decision about holding the bus that has already reached the transfer point. The advantage of driver reporting is that the dispatcher or supervisor can consider prevailing circumstances when making decision that is best under the circumstance. Such decisions are likely to be better than the a fixed pre-specified holding option that must be followed by drivers regardless of the circumstance. Disadvantages of driver reporting are: drivers may not be always report late buses when they should; drivers may not report vehicle status accurately; and drivers may not report vehicle status in a timely manner.

Real-Time Dispatching Control

Real-time information from AVL can be used to implement real-time dispatches at transfer points. With AVL, bus arrival times at a transfer point can be forecasted every time the bus passes each time point. This would enable the control center to perform real-time optimization of vehicle holding option and holding time for each bus at the transfer point, taking into consideration both transfer and non-transfer costs. Real-time optimization of vehicle dispatches at the transfer point would be further enhanced if the AVL also has the capability to provide the numbers of onboard passengers and passengers wishing to transfer. The control center can inform drivers of all buses regarding the holding decision via the driver display unit on board each bus. Alternatively, an "intelligent" bus stop can send such a message to the driver display unit of each connecting bus that arrives at the transfer point.

Hall et al (1997) tested various vehicle holding options with and without real-time information, through simulation. They reported that real-time vehicle dispatch options resulted in smaller passenger delays and waiting times than options without real-time information.

CHAPTER FIVE

A FRAMEWORK FOR EVALUATING BENEFITS AND COSTS OF CONTROL STRATEGIES TO IMPROVE TRANSIT PERFORMANCE

AVL represents the application of an evolving high technology in which transit operations and control strategies are introduced through integrating information on vehicle performance and location. The evaluation of the potential impacts of AVL must consider how AVL affects these strategies and operations. The evaluation of the potential impacts *with* and *without* AVL provides important input for the agency to select the most promising strategy for further detailed study and implementation. The natural extension to this evaluation process is the identification of the benefits/impacts of alternative control strategies utilizing AVL.

Details of the value and contribution of AVL systems to productivity improvements, cost reductions, service delivery of fixed-route transit and ADA-type paratransit services, ridership and revenue are needed before investment decisions in AVL can be made. This includes decisions on: whether to invest in AVL; which type of AVL technology to select; what level of investment to choose and the timing of any such investments and, benefits/impacts of alternative control strategies utilizing AVL.

This manual is a stand alone document that can be used by transportation professionals at transit agencies to evaluate AVL using the information and methodology base developed in the main report to create an operations manual for the evaluation of AVL. The evaluation framework must address the following:

- What is the relationship between the objectives and the impacts of benefits and costs?
- What measures are to be used for benefits, costs and impacts?
- How are the measures of effectiveness to be evaluated?
- How does this information fit into the transit agency's management decisions?

The information required for the alternative decision models, impact analysis, cost-efficiency analysis and benefit-cost analysis is essentially common, although any one of the methods may use only a subset of information. Once the information is collected and the quantities of benefits and costs are measured, meaning a value is placed on them, they need to be evaluated by a decision rule. The details of these decision criteria are discussed at length in the main report but are simply reported below.

Objectives, Impacts and Measures

At the present time, four prime objectives for the introduction of AVL have been identified by transit agencies in the U.S. They are:

A. Schedule adherence and timed transfers.

B. Emergency and incident management.

C. Passenger information.

D. Data for transit management and planning.

Each of these objectives is affected by AVL in one or more ways. The impacts can be felt by the (a) transit agency and their personnel, (b) transit users and (c) by the broader community.[1] In this operations manual the focus will be on agency and user impacts, principally because the impacts can be measured or at minimum quantified. Some if not many community impacts can be identified but not necessarily quantified or are at least open to greater measurement errors than impacts in the other two areas.

Any evaluation requires the identification of the relevant comparison, the measurement of the impact, identification of the time stream of the impact and the valuation. The detailed steps required in any evaluation regardless of the decision model chosen include:

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[1] One might argue, for example, that AVL can lead to more uniform route speeds leading to a reduction in some types of pollution. This would represent a community impact.

1. establish the baseline from which all other measures are taken and to which the comparison will be made.
2. determine the additional capital costs for station, agency and vehicles
3. estimate the additional annual variable costs (labor, maintenance, training)
4. estimate the agency benefits from each category of impact
5. estimate the user benefits for each category of impact
6. for each of the cost and benefit categories, estimate the length of time the costs or benefits will accrue
7. determine the appropriate rate of discount and discount each of the benefit and cost categories to the present
8. use the benefit or costs or both in the chosen decision model to evaluate the new technology using some accepted decision rule such as net present value, internal rate of return or benefit-cost ratio.

Step 1. Establish a Baseline Measure for Comparison

Any evaluation of a proposed AVL investment must be compared to something. This ‘something’ is called the baseline or counterfactual. Generally the baseline is taken to be the status quo. It is established by asking the question, “what would be the agency costs, the level of ridership, the amount of time riders would wait, would travel in-vehicle and would walk to transit stops if the transit system were to continue operating in the future as it is today”? This step is forgotten in many cases yet forms a key part of any analysis. It is the alternative for comparison with a proposed AVL project or control strategies utilizing AVL, and is used in selecting from among AVL projects as well. Even the case in which two AVL control strategies are being compared for selection the impacts have to be measured from some perspective.

The data that should be available for the baseline (status quo or no AVL control) analysis includes:

- total vehicles
- transit operating expenses
    - vehicle operations expenses
    - vehicle maintenance expenses
    - non-vehicle maintenance expenses
    - general & administrative expenses
    - purchased transportation
- transit service characteristics
    - fleet size
    - vehicles operated in peak
    - vehicles operated in base
    - growth in vehicles operated in peak and base
    - vehicles operated - maximum service

  - vehicles available - maximum service
  - route miles
  - number of employees
  - number of employee hours
  - number of road calls
  - number of service interruptions
- transit safety
  - number of incidents (collision, non-collision, station)
  - number of fatalities (patron, non-patron, total)
  - number of injuries (patron, non-patron, total)
- transit service supplied
  - scheduled and annual vehicle revenue miles
  - actual annual vehicle miles
  - actual annual vehicle hours
  - actual annual vehicle revenue miles
  - actual annual vehicle revenue hours
- transit service consumed
  - annual unlinked passenger trips
  - annual passenger miles
  - passenger delays

Agency costs need to be divided between fixed costs and variable costs. This can be accomplished if costs are broken out into capital expenditures (separately for fleet, routes, headquarters and other), maintenance costs (separately for administrative, labor, materials, energy and other), vehicle operating costs, route operating costs (separated for vehicles, drivers, maintenance) and agency operating costs (administration, labor [e.g. dispatchers], maintenance personnel, management, other).

Agency performance measures should be constructed and be linked to either costs or ridership or both. The change in the performance measures can be readily utilized in any project assessment. Some suggested measures of transit performance could be:

Fleet utilization: passenger trips per revenue vehicle hour or mile

Revenue generation: operating revenue per dollar of expenses

Labor productivity: total vehicle hours (or miles) per employee or revenue vehicle hour (or miles)per employee or revenue passengers (or revenue passenger miles) per employee

Vehicle efficiency: total vehicle miles (or hours) per peak vehicle or total vehicle miles per vehicle

Maintenance efficiency: total vehicle miles per maintenance employee, total vehicle mile per maintenance dollar, fleet utilization per maintenance employee

Safety: incidents per route mile (or operating hour), vehicle miles per dollar of insurance or incident delay per scheduled route time or accidents (injuries) per vehicle mile or vehicle hour

Cost efficiency: total cost (and total variable cost and total operating costs) per vehicle mile, vehicle hour and revenue passenger

Service levels: passengers per vehicle mile, # of service calls, # service interruptions

Revenue generation: revenue/passenger, revenue/vehicle mile, revenue per route, revenue for route cycle[2]

Agency output or service delivery must contain sufficient detail that AVL effects can be calculated. Measures that might be included would be total passengers, total vehicle miles, passengers/vehicle (peak and off-peak), passengers/route, average route time (peak and off-peak), route headway (peak and off-peak) and some measure of the degree of schedule adherence.

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[2] The amount of fare-box revenue collected for each complete cycle of a given route

Step 2: Measure the Agency Cost Impacts

The AVL project will require investments in physical capital, computer hardware and software, personnel training - some perhaps on an ongoing basis- additional maintenance, changes in personnel and procedural changes. In each case the added costs that are a direct or indirect result of the project must be accounted for. Furthermore, costs that are going to occur in the future must be identified and the period over which the will accrue needs also to be identified. For example, if a contract is let to some firm for maintenance of the AVL equipment and the contract is of some value over the next 10 or so years, these costs will need to be discounted.

The key feature that will determine whether a cost should be included in any evaluation of an AVL project is *that the cost would be avoidable* if the AVL project did not occur. Costs that are on ongoing liability of the agency regardless of whether the AVL project is undertaken or not should not be included. Similarly, R&D costs that have been incurred prior to the project

The impacts of an AVL investment is illustrated in Figure 5.1 below. The benefits are shown to be accruing to [transit] users and the transit agency itself. These two impact groups should be treated separately since the impact types are quite different. The primary beneficiaries will be with the latter group. The source will be improvements in productivity of vehicles, drivers and maintenance. The ability to produce the same services with fewer vehicles will reduce the need for drivers and for maintenance. An apparent minor source of benefits will accrue to users. While it is true that AVL control strategies can result in time savings through better connections and a reduction in the variability of schedules allowing transit users better trip planning, it is not clear how this will affect ridership. Certainly existing users will be better off (provided fares do not rise) since their service has improved.[3] It really is an empirical question whether the improvements in service will lead to additional ridership and hence added revenue for the agency.

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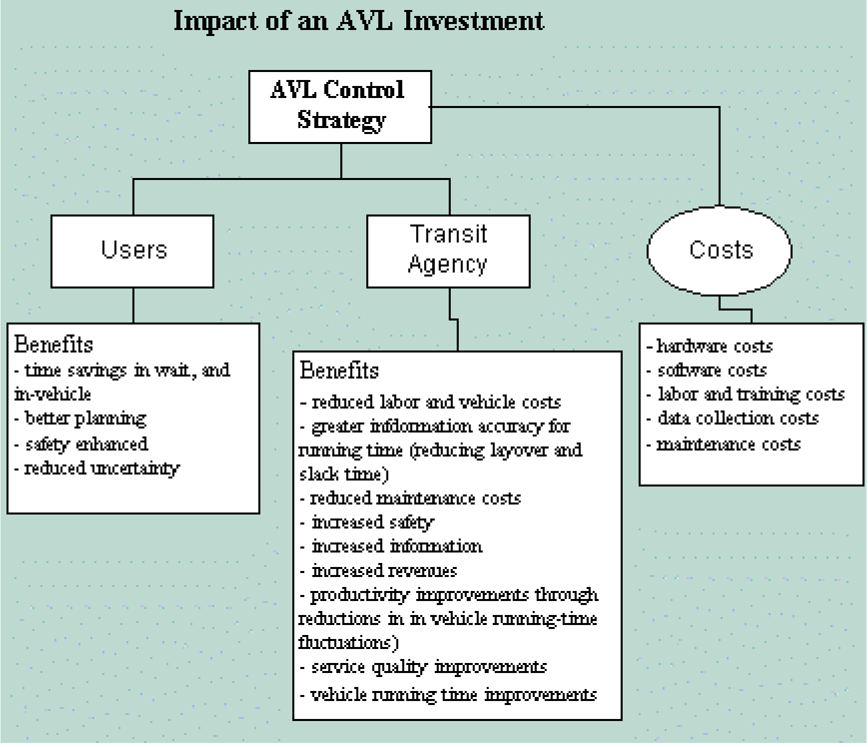
[3] This benefit would be measured by an increase in consumer surplus. It represents a real welfare gain and should be counted in benefit calculations.

Figure 5.1



Step 3: Measuring the Benefits to the Agency

Agency impacts that arise from the implementation of an AVL control strategy can be generally classified into three categories; **(1)** increased productivity or efficiency, **(2)** lower costs (holding service constant) and **(3)** improved service (holding costs constant).

In Table 5.1 the set of [potential] impacts on the transportation agency are categorized, described in terms of their primary area of impact and for each a detailed

Table 5.1

Agency Impacts and Measures

Objective	**Impact on Agency**	**Measures**	**Calculation**
(1) Schedule Adherence and timed transfers	vehicle utilization rates (+)	revenue vehicle hrs (RVH)	(RVH/day)$_{t+n}$ - (RVH/day)$_t$
		revenue vehicle miles (RVM)	(RVM/day)$_{t+n}$ - (RVHMday)$_t$
	Monitoring driver performance	deviation from scheduled time (avg. over shift)	(actual trip time over defined segment - scheduled trip time defined segment) x (# trips)
	reduced fleet requirements	capital, driver , maintenance, fuel savings	% fleet reduction x (cost per vehicle + maintenance per v +drivers per vehicle + operating cost per vehicle)
	Driver Costs	reduced overtime	# drivers x reduced overtime per driver x cost per unit overti
	transfer co-ordination (+)	lower monitoring costs	Δ # of monitors x annual wage
		lower scheduling costs	Δ # scheduling personnel x wage
		fewer dispatchers	Δ # of dispatchers x annual wage
	coordination with other modes (+)	integration with specialized transit services	cost reduction in personnel
	fewer grievances (+)	reduced office staff	Δ # office personnel x wage
(2) Emergency & Incident Management	Ability to direct vehicles enroute (+)	reduced vehicle delay	schedule adherence (see user impacts)
		reduced labor costs and reduced costs for additional vehicles	savings in wages, maintenance and fuel expenses
	Incident management (+)	faster response and management	savings in incident management costs lower insurance costs
(3) Passenger information (vehicle arrival time at stops and expected travel time onvewhicle)	costs of providing (-)	hardware costs	# stops x cost per stop
		updating & information maintenance	annual wage x # personnel
(4) Transit Operations Information	data collection costs (-)	develop & implement MIS system	hardware costs + operations cost (labor x wage x years)
	lower ride check costs (Sec 215) (+)	lower preparation, collection costs	wage x # personnel reduced
	lower transit management costs (+)	lower preparation, collection costs	wage x # personnel reduced
	lower costs of performance improvements	lower report preparation costs	managers and line supervisors time (increased productivity)

Table 5.1 (continued)

Agency Impacts and Measures

Objective	Impact on Agency	Measures	Calculation
(4) Ridership	revenue impacts[4]	demand response to increased scheduling	% change in ridership x fare per rider
		demand response to higher safety	% change in ridership x fare per rider
		demand response to greater certainty	% change in ridership x fare per rider
		demand response to lower waiting time	% change in ridership x fare per rider
		demand response to lower in-vehicle time	% change in ridership x fare per rider

Note: the ridership impacts are considered to be less likely to occur particularly in the short term. There is some evidence cited in the report that there is some small impact on increasing ridership but a conservative calculation should be undertaken until more evidence is available from research studies.

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[4] This measure is an underestimate of the true economic benefit since it excludes added consumer surplus to existing riders and new riders. A measure of the demand elasticity and some assumptions as to the expression of the demand function would be required to make the consumer surplus calculation.

method of making the calculation is listed. The organization of the table follows the listing of objectives catalogued earlier. These impacts that are identified are certainly not exhaustive but represent the most likely consequences. They can be calculated using the formulas contained in the 'Calculation' column. What is clear from this table and the detailed formula is the evaluation, to be comprehensive, is relatively data intensive. This should not deter an evaluation, however, since the data are no different than those that are needed in establishing the base case.

As it was stated earlier, the primary sources of agency benefits come about from improvements in fleet utilization, improvements in efficiency from the various categories of labor and the potential for reducing the number of vehicles (and their attendant drivers, maintenance requirements etc.) with no reduction in service.[5] The difficulty is that the specific relationships between the AVL control strategy and the improvement in cost and productivity are not well known. AVL represents a new technology and the effects are not well documented, quantitatively.

What is needed is a method of establishing the simple statistical relationships between costs and fleet reductions and revenue mile reductions and fleet requirements and schedule

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[5] It is also possible to translate this impact into a service level improvement but without and additional resources required.

adherence. These would provide a means whereby it would be possible to measure the costs savings. More specifically, the impacts of AVL can more easily be calculated with information on the following relationships[6]:

The first equation attempts to link the size of the fleet of transit vehicles (fleet size) to a set of variables that can be impacted by AVL control strategies. These would include schedule adherence, number of revenue vehicle miles and other variables that would impact fleet size. The key variable for evaluation purposes is the schedule adherence. If it were possible to obtain information on these variables over time and across a number of transit agencies, it would be possible to 'estimate' values for b_1 as well as b_2 and the 'b_i's'. The importance of knowing b_1 is that it provides a measure of the change in (or impact on) fleet size with a unit change in the schedule adherence, holding other things constant (or controlling for the other influences).

$$\text{Fleet Size} = a + b_1 \text{(schedule adherence)} + b_2 \text{(revenue vehicle miles)} + \Sigma\, b_i \text{(other variables)} \qquad (1)$$

In equation 2 a similar exercise is carried out as it was for equation 1. It is trying to understand what factors are most important in determining total operating costs. Notice there is a linkage between equation 1 and equation 2. The variable 'fleet

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[6] The relationships are represented as linear but there is no reason they necessarily should be.

size' appears in both equations but in equation 1 it is the variable that 'is being explained' while in equation 2 it is an 'explaining' variable. As in the case of the first equation, if there are enough data available to 'estimate' values of c, d_1, d_2 and d_3 using regression techniques, it is possible to determine how changes in fleet size will alter total operating costs. Therefore it would be possible to assess how the introduction of an AVL control strategy would affect operating costs using both equations 1 and 2.

$$\text{Total Op. Cost} = c + d_1\,(\text{revenue vehicle miles}) + d_2\,(\text{fleet size}) + d_3\,(\text{number of transferring routes}) \qquad (2)$$

In equation 3, the effect of the 'variance in schedule adherence' on output as measured by vehicle miles is examined. There are two important relationships here. First, is the direct effect of changes in AVL control strategies on vehicle miles. The parameter h_1 would measure how many added vehicle miles a transit firm could achieve with an improvement in schedule adherence. This is an improvement in output (hence performance) with no additional resources save those associated with the AVL strategy. There is also an indirect effect through the impact on total operating costs, equation 2. The sequence would run from the AVL control strategy affecting schedule adherence that has an impact on vehicle miles which in turn has an effect on operating costs.

$$\text{Vehicle Miles} = g + h_1 \text{ (variance in schedule adherence)} + \Sigma\, h_i \text{ (other factors)} \qquad (3)$$

In equation 4, the impact of AVL on one aspect of transit performance or service delivery of the transit firm is being explored. AVL control strategies can have an impact on schedule adherence and this can manifest itself in either lower costs or greater output or levels of service with no additional resources. The first three equations explored how AVL can result in lower costs either directly or through enhancements in productivity. In this equation the relationship is much more how output can be increased with no added resources except those expended on the AVL control strategy. If AVL improves schedule adherence it will allow the transit firm to use its existing resources to raise the level of service. This will have an impact on transit users and would certainly be counted as a benefit of the AVL system.

$$\text{Revenue Miles} = e + f_1 \text{ (\# of routes)} + f_2 \text{ (\# transfer points)} + f_3 \text{ (schedule adherence)} \qquad (4)$$

These four relationships are just a beginning in establishing relationships that provide insight as to how AVL control strategies effect transit efficiency and performance. The equations set out will identify the fleet reduction available with changes resulting from AVL, the reduction in revenue miles available with AVL and how cost would change with changes in revenue miles.

Information and Evidence from the Literature

A review of the research and technical economics literature implies that the primary agency benefits resulting from AVL control strategies are reduced fleet costs due to higher productivity, reduced operating costs and some small potential increased revenue from increased ridership.[7] A recent study (Benefits Assessment of Advanced Public Transportation Systems (APTS), 1996) provides a set of measures of the gains from implementation of AVL systems in different locations in North America. The values reported below are averages or ranges reported from American and Canadian cities. Unfortunately how the benefits were realized is not documented for the cases only the end result was reported.

Earlier the identification of the reduced fleet requirements was identified as a major benefit from AVL. The reduction in fleet requirements as a result of greater fleet utilization because of closer schedule adherence has been found to be between 2-5 %. This is a non-trivial amount. The costs savings would be even greater than this as driver, maintenance

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[7] There is mixed evidence on the revenue effects. Some argue that the improvements in transit service are sufficiently small that no additional ridership will result from an AVL control strategy. Others however, notably economists, have argued that empirical estimates of the sensitivity of ridership to key demand variables such as time and reliability is non-zero. Therefore, the impact on revenue and ridership should not be ignored. The question is an

and operating costs would also be saved for each vehicle reduction in the fleet. This can be measured as:

Reduced fleet cost = # vehicles x capital cost/vehicle x % reduction in fleet (5)

Schedule adherence[8], as was identified above, has two separate effects. On the cost side it leads to productivity improvements as just identified. However, it also leads to demand side benefits. The improvement in schedule adherence has been found to range from 23-90% which is a significant amount. The increase in ridership revenue as a result of improvements in transit service quality resulting from schedule adherence range from 0.5 - 3%. A measure of the [potential] revenue impact can be calculated as:

Change in Transit Revenue = # annual transit trips x % change in passenger trips x average fare per trip (6)

Quite separately from these other effects, a reduction in operating costs have been identified as another source of benefit. The operating cost per *vehicle mile* have been found to have decreased by 8.5%, while operating cost per *vehicle hour* decreased by 8.6% and operating cost *per passenger* has decreased

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empirical one.

[8] Unfortunately the measure of schedule adherence is not identified; that is, the parameters used to measure the change are not explained in any detail.

up to 2.2%.[9] These represent three different means whereby operating cost savings can be calculated. Furthermore, the change in vehicle miles has ranged from 5-8%. It is therefore possible to use this information to calculate [likely] reductions in operating costs. The calculation would be:

Reduced Total Operating Cost = (operating cost/vehicle mi.) x (% decrease in operating costs) x (total vehicle mi.) x (% reduction in total vehicle miles). (7)

Step 4: Measuring the Benefits to Users

The majority of benefits to the users will show up as reduced time used in trip-making due to improvements in the quality of transit service. This will be realized in reduced waiting time, reduced transfer time and reduced in-vehicle time. In order to complete the calculations, measures of the elasticity or responsiveness of ridership with respect to changes in travel time (distinguished by source), the percentage change in time and the valuation of the time are required. For example, if it was found that transit ridership was sensitive to reliability and that if reliability improved by 10 percent ridership would increase by 4 percent, the benefits could be calculated using this measure.[10]

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[9] These cost reductions would apply to DIAL-A-RIDE and special dedicated transit service and not scheduled service.

[10] This essentially says the elasticity of ridership with respect to changes in reliability is .3.

Step 5: Discount Rates and Valuations

The calculation of future costs and benefits must be discounted. As well decision rules require the use of discount rates to evaluate the decision. In both cases an interest rate must be selected. The 5 or 10 year Treasury Bill yield is most commonly selected. The discount rate should reflect a long term cost of capital, it should also take account of any inflation. In the current environment with negligible inflation the nominal interest rate is adequate.

The two key valuations are value of time and value safety. Numerous studies have been undertaken to measure each of these and there is a significant degree of variability. The average across all studies is 60 percent of the wage rate. Based only on US studies this figure is 20 percent of the wage. The FHWA is using 60% of the wage for highway evaluation while California uses $7.42/vehicle-hr. The ratio of work to non-work time valuation is 4:10; if the wage were $10.00, the value of work time would be $6.00 (60%) and the value of non-work time would be $2.40 (40% of work time valuation). Since an AVL would be implemented for the entire transit coverage area, the most reasonable approach is to use the 60 % of the wage rate for the urban area.

AVL can also result in improvements in safety. While this does not refer to probabilities of injury, it does have a positive utility affect on riders and should be included in the valuation. This could be treated as an improvement in the value of time by some small percentage.

Step 6: Decision Rules

Benefit-Cost Analysis

An essential and often difficult task is to determine the pattern of benefits and costs over the project's life, but once accomplished, the analyst has a time stream of benefits

$$B_0, B_1, B_2, \dots , B_{t-1}, B_t$$

and a time stream of costs

$$C_0, C_1, C_2, \dots , C_{t-1}, C_t$$

from the present period, 0, to the termination date t or some future point such as the lifetime of the project. B_0 is the benefits in the current year, B_1 the benefits next year and so on until B_t are the benefits in year t. Similarly for costs, C. The money value of the respective time stream cannot simply be summed and compared to determine the project's viability since the time patterns of benefits and costs are likely to differ. Usually the bulk of the costs occur in the early years when the investment is first made, while benefits are generated over a number of years once process becomes operational. The difference in the timing of benefits and costs would not matter if people valued a dollar today and a dollar in the future equally.[11]

Because a dollar is valued differently at different periods of time, it is necessary to relate the value of benefits and costs in different years to a common period. This is done by *discounting future benefits and costs* to their present value. The present value of one dollar available in period t and discounted at the rate i is [12]

$$PV = \$1/(1+i)^t$$

Hence the present value of the benefit stream can be established as

$$PV_B = \sum B_t/(1+i)^t$$

and the present value of the cost stream is calculated in precisely the same way as

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[11] However, they do not, as evidenced by the fact that borrowers are willing to pay interest, a premium for the use of money today rather than waiting for the future, while lenders require the interest as compensation for foregoing their use of money today and postponing its use until the future. This is the reason that we find, for example, that a $1,000 bond payable one year hence has a market value of $925.93 when the rate of interest is 8 percent.

[12] This is easily calculated using any common spreadsheet program such as Excel© or Lotus© or Quatro©.

$$PV_c = \Sigma\, C_t/(1+i)^t$$

Once discounted to the present, benefits and costs can be compared. In CBA this comparison is most commonly expressed either as a benefit-cost ratio

$$B/C = \Sigma\, B_t/(1+i)^t \,/\, \Sigma\, C_t/(1+i)^t$$

or as net present value

$$\text{Net NPV} = \Sigma\, (B_t - C_t) / (1+i)^t$$

The project is viable on economic efficiency grounds if the B/C is greater than one or if its net present value is positive.[13] The former value provides a measure of the rate of return; the benefits per dollar of expenditure. The latter gauge gives a measure of the magnitude of the return; how big it is in dollars.

The major advantage of the net present value (NPV) criterion is that it shows the absolute magnitude of the returns from a project. This is in contrast to the benefit-cost ratio (B/C) which only reflect relative returns. Absolute magnitudes, while an essential consideration, are not the whole story for projects with the same dollar benefits ($10M, for example) may have much different relative returns. For example, $10M net benefits might accrue from projects with benefit-cost ratios of $20M/$10M = 2, or $200M/$190M = 1.05. As a result, one cannot usually select projects on the basis of a single criterion, as both absolute and relative measures deserve consideration.

After consideration of these criteria and their relative merits, the reader may wonder which of these is the appropriate one to employ and rightly so, since no one is ideal and each offers some advantage in certain circumstances. Generally, however, the preference is to use of the B/C ratio in conjunction with a net present value measure. This provides measures of both the absolute magnitude of discounted net benefits as well as the 'rate of return'.

Cost Effectiveness Analysis

Cost effective analysis [CEA] is commonly used as an alternative to CBA. CEA evaluates a potential application of AVL measuring the extent to which it may achieve a given goal within a predetermined budget or, equivalently, it compares the costs of achieving a particular goal using AVL and non-AVL technologies. Often, the goal will have been set under a

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[13] These two expressions, as well as internal rate of return, are discussed in detail in the section "Project Selection Criteria."

separate process in which benefits and costs may have not been considered.

CEA compares, usually mutual exclusive, alternatives on the basis of their costs and a single qualified but not monetized effectiveness measure, such as number of lives saved, or number of minutes of travel time saved or amount of agency costs saved.[14] Though there is no conceptual reason why costs cannot be measured comprehensively, in practice analysts generally measure them narrowly as budgetary costs.[15] CEA makes the assumption that the project should be undertaken and what is being sought is the most cost-effective way of accomplishing this. It does not provide information as to whether there are positive net social benefits associated with any of the alternatives.

Cost-Effectiveness Ratios

There are two basic ways to create cost-effectiveness ratios. For decision-making purposes there are two ways to impose constraints to facilitate comparison of policy alternatives involving projects of different scales. There are also adjustments that can be undertaken to make CEA closer to CBA.

Since CEA does not monetize benefits, it inevitably involves two different metrics: cost in dollars and an

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[14] Clearly, the development of performance measures is essential for the application of CEA to ITS.

[15] Thus social costs are generally excluded yet some AVL impacts may have an impact on congestion or air quality.

effectiveness measure - for example, reduced travel time, increased safety, lower transactions costs. Because non-commensurable metrics cannot be added or subtracted, it is not possible to obtain a single measure of net social benefits from the two metrics. It is only possible to compute the ratio of the two measures as a basis for ranking alternative policies. This can be accomplished in two ways.

First, cost-effectiveness can be measured in terms of cost per unit of outcome effectiveness, for example, cost per minute of travel time saved. To compute this, one takes the ratio of the budgetary cost of each alternative I, denoted by C_i to the effectiveness (or benefit) of that alternative, E_i.

$$CE_i = C_i/E_i$$

This CE ratio can be thought of as the average cost per unit of effectiveness. The most cost-effective project has the lowest average cost per unit of effectiveness. Therefore, projects should be rank ordered from the most cost-effective, those with the smallest CE ratio, to the least cost-effective.

Second, cost effectiveness can be calculated as the ratio of the outcome effectiveness units per unit of budgetary cost, or:

$EC_i = E_i/C_i$

This EC ratio can be thought of as the average effectiveness per unit of cost. The most cost-effective project has the highest average effectiveness per unit of cost. Thus, projects should be rank ordered from the most cost-effective (those with the largest EC values), to the least cost-effective.

Example of AVL for Santa Clara County

The evaluation process can be illustrated using information from Santa Clara county It would be valuable to undertake a study of control strategies to improve schedule adherence.

The following different strategies could be evaluated:

- establish baseline values for all variables

Low technology

- Introduce slack time in schedule (full or selected segments)
- Hold, skip stops
- Driver incentives in training
- Decrease route length

High technology (using AVL)

- Signal preemption for very late vehicles
- Real-time hold, skip stops and add-buses
- Real-time timed transfers
- Advanced real-time information for passengers at stops and/or onboard buses.

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